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Swelling of Four Glove Materials Challenged by Six Metalworking Fluids

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Abstract The performance of protective gloves against metalworking fluids (MWFs) has rarely been studied because of the difficult chemical analysis associated with complex MWFs. In the present study, glove swelling was used as a screening parameter of glove compatibility after challenge of the outer surfaces of chloroprene, latex, nitrile, and vinyl disposable gloves by six MWF concentrates for 2 hours in an ASTM F-739-type permeation cell without collection medium. Swelling relative to original thickness was up to 39% for latex, 7.6% for chloroprene, and 3.5% for nitrile. Shrinking up to 9.3% occurred for vinyl. Chloroprene and latex did not swell significantly for the semisynthetic and synthetic MWFs. Vinyl, previously not tested, was a good candidate for MWFs other than the soluble oil type. Although nitrile was recommended by the National Institute for the Occupational Safety and Health (NIOSH) for all types of MWFs, its swelling after 2-hour challenge was significant with Student *t*-tests for the soluble oil, synthetic, and semisynthetic MWFs. Glove swelling can be used as a screening chemical degradation method for mixtures such as MWFs with difficult chemical analysis. Further studies need to be conducted on the relationship between permeation and glove swelling.

Introduction

Metalworking fluids (MWFs) improve machining performance and prolong tool life (NIOSH 1998). The National Occupational Exposure Survey in 1981–1982 estimated that 1.2 million workers in the United States were potentially exposed to MWFs (NIOSH 1998). Independent lubricant manufacturers in the United States produced 92 million gallons of MWFs in 1990 (McCoy 1994). The estimated use in North America exceeded 2 billion gallons in 2000 (Independent Lubricant Manufacturers Association 2000).

The four major types of MWFs are straight oil, soluble oil, semisynthetic, and synthetic (NIOSH 1998). Straight oil MWFs are essentially 100% refined distillates of petroleum (commonly called mineral oils) or of vegetable oils, with bactericides, extreme pressure additives, and other additives. Soluble oil, semisynthetic, and synthetic MWF concentrates are diluted with water before use. They contain up to 85%, 5%–30%, and 0% oil content, respectively, with the remainder being water and other additives such as surfactants, fungicides, bactericides, extreme pressure additives, and corrosion inhibitors (Byers 1994; NIOSH 1998; Glaser *et al.* 2003).

The major MWF exposure routes are inhalation and dermal absorption. MWF exposure in the workplace causes respiratory disorders including coughing, chest tightness, and asthma (NIOSH 1998). NIOSH recommends that exposures to MWFs be limited to 0.4 mg/m^3 of air for thoracic particulates, or 0.5 mg/m^3 of air for total particulates as a time-weighted average concentration for up to 10 hours/day during a 40-hour workweek (NIOSH 1998). Before the mid-1970s, MWFs were associated with increased risks of laryngeal, rectal, pancreatic, skin, scrotal, and bladder cancer (NIOSH 1998). "Severe" treatments of

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mineral oils to minimize polyaromatic hydrocarbons have been instituted since the 1950s, followed by further treatments to reduce carcinogenic nitrosamines in the 1980s (NIOSH 1998). Given the long cancer latency period, available data are still inadequate to conclude whether these changes have eliminated or decreased the cancer risk (Apostoli *et al.* 1993; NIOSH 1998).

While much attention has been focused on air sampling and cancer, many exposed workers (14% to 67%) suffer irritant or allergic contact dermatitis (NIOSH 1998). Protective rubber gloves are worn to reduce dermal absorption and to protect the skin. Nitrile gloves have been recommended by NIOSH (1998), based on limited permeation data provided by Forsberg *et al.* (1986). Our research group has investigated permeation of MWFs through gloves (Xu and Que Hee 2004, 2006a, 2006b, 2007). A recent study reported that a disposable nitrile glove performed well for 0.5 hour against a straight oil MWF (Xu and Que Hee 2006b).

The performance of protective gloves against a mixture needs to be determined by direct testing (NIOSH 1998). Permeation of mixtures often deviates from additivity of the pure liquid component parameters on a mole fraction basis (Perron *et al.* 2002). Papers on glove performance against MWFs (Forsberg *et al.* 1986; Xu and Que Hee 2006b) are few, probably because of the quantitation difficulties posed by these complex chemical mixtures. Mineral oils, the common major components of MWFs, cannot be resolved even with modern chromatographic techniques (Anderson *et al.* 2003). Alkanolamines, unspecified chloroparaffins, and polyglycol ethers are also commonly listed in the material safety data sheets (MSDS) of MWFs. Many additives, such as di-*n*-octyl disulfide (Xu and Que Hee 2006a), 4-chloro-3-methylphenol (Brown and Arnold 2005), 5-methyl-1H-benzotriazole, and 1-octanoic acid (Xu and Que Hee 2004), are not listed because of trademark protection.

In addition to permeation and penetration, degradation of glove materals is often used to evaluate glove performance (Anna 2003). Some degradation parameters include hardness, stiffness, brittleness, and swelling (Ansell 2003). Efforts to model the permeation of a chemical from its solubility in glove materials have achieved some success (Anna 2003). During permeation, a challenge compound is first adsorbed to the outer surface of the glove, then it diffuses/dissolves in the glove material, and finally it reaches and desorbs from the inner surface of the glove (Georgoulis *et al.* 2005). Glove swelling or shrinking may occur at the absorption step. Swelling continues until the elastic retraction of the polymer chains (backbones) balances the osmotic pressure driving the compounds into the material (Aithal and Aminabhavi 1991). Glove swelling has been used to determine the amounts of solvent permeating into glove materials over time (Perron *et al.* 2000). Volume changes after long-term immersion of polyvinyl chloride and natural rubber glove materials in liquefied coal correctly predicted the relative breakthrough characteristics of liquefied coal (Bennett *et al.* 1983). Swelling increases the free volume between the backbones of the polymer and “opens the meshes of the network” (Xiao *et al.* 1997; Barriere and Leibler 2003), and may increase the permeation rate of the challenge compound that caused the swelling (Xiao *et al.* 1997), along with components that did not cause the swelling (Barriere and Leibler 2003; Georgoulis *et al.* 2005), the so-called “co-solvent” effect. Swelling could affect the permeation and penetration of a challenge mixture through glove materials. Consequently, glove thickness changes and other physical changes may serve as screening indicators of glove potential protectiveness against MWFs. At the very least, thickness changes are related to chemical compatibility with the glove material, and therefore predict degradation. Given the analytical chemistry complexities, much less cost and time would be required by this screening approach to evaluate more MWFs and gloves.

In the present paper, thickness changes of representative disposable gloves of four major polymer types (latex, nitrile, vinyl, and chloroprene) are measured. Disposable gloves were tested, because they are preferred by workers and they provide better dexterity and user comfort than chemically protective analogs. Even though these gloves may only be used to protect against incidental splashes (Boman *et al.* 2005), many workers tend to continue using contaminated disposable gloves instead of discarding them.

MWF concentrates were used to challenge gloves because the results with concentrates will be more protective for workers exposed to MWFs diluted with water, except when polyvinyl alcohol gloves are used. Previous studies found that a malathion pesticide formulation concentrate broke through nitrile and permeated at a higher rate than its diluted aqueous solution (Lin and Que Hee 1998a). Nielsen (2005) also noted that the more lipophilic the formulation and the less water content the pesticide formulations have, the more rapidly pesticides permeate vinyl, nitrile, and latex/neoprene gloves. It is thus expected that undiluted soluble oil, semisynthetic, and synthetic MWF concentrates will potentially permeate more through nonpolar gloves than their diluted aqueous solutions.

Methods

Materials

Six comercially available MWFs (one straight oil type, two soluble oil type, one semisynthetic MWF, and two

Table 1 The metalworking fluids (MWFs) used in this study

MWF type	Trade name	ID[a]	Manufacturer (address)	Components listed in material safety data sheets		
				Listed name	CAS number	Listed weight percent
Straight oil	Deolene D-4	STO	WS Dodge Oil (Maywood, CA)	Mineral oil (petroleum hydrocarbon)	64741-97-5	"Various amount"
Soluble oil	Cool-Flow 1020	SO1	ATW (Mechanicsville, VA)	Heavy naphthenic, severely hydrotreated, chemically neutralized oil	64742-52-5	60–65
	Cimperial 1070	SO2	Milacron (Cincinnati, OH)	Severely-hydrotreated naphthenic petroleum distillates	64742-52-5	40–70
				Monoethanolamine	141-43-5	5–10
				Polyethoxylated propoxylated alcohol	69227-21-0	1–5
				Polychlorinated alkanes	None assigned	up to 15
Semisynthetic	Cimstar 30	SES	Milacron (Cincinnati, OH)	Severely hydrotreated naphthenic petroleum distillates	64742—52—5	7–13
				Petroleum sulfonic acid, sodium salt	68608-26-4	1–5
Synthetic	Cool-Flow SYN	SY1	ATW (Mechanicsville, VA)	Triethanolamine	102-71-6	3–5
	Cimtech 95	SY2	Milacron (Cincinnati, OH)	Triethanolamine	102-71-6	5–10
				Monoethanolamine	141-43-5	1–5
				Neodecanoic acid	26896-20-8	1–5
				Nonanoic acid	112-05-0	1–5

[a] Identifier of a specific MWF in the text

synthetic MWFs) were purchased from their manufacturers. Their trade names, manufacturers, components listed in their MSDS, and their identifiers in this paper are listed in Table 1.

Four disposable glove types (one nitrile, one latex, one chloroprene, and one vinyl) were evaluated in this study. They were all purchased from Fisher Scientific (Pittsburgh, PA). Their trade names, manufacturers, and structural information (Mellstrom and Boman 2005) are listed in Table 2.

Challenge Procedure

Out-of-the-box gloves were conditioned for 24 hours in a desiccator, where the relative humidity was maintained at 55 ± 1% by saturated aqueous sodium dichromate. Gloves were then challenged by MWFs in a procedure based on the standard American Society for Testing and Materials (ASTM) F739-99a permeation method (Lin and Que Hee 1998a, 1998b; ASTM 2004; Xu and Que Hee 2006b). Circular glove pieces of 42.5-mm diameter were cut from the glove palms, and their thickness measured. Each piece was then held between the two Teflon gaskets and the Pyrex chambers of an I-PTC-600 ASTM-type permeation cell (Pesce Lab, Kennett Square, PA) by a uniform torque, with the outer surface of the glove facing the challenge chamber. The test area of the glove between the two chambers had a diameter of 25.4 mm. A 10-mL volume of MWF was pipeted into the challenge chamber, and the collection chamber was left empty. Controls with both chambers empty were also performed. Seven permeation cells were immersed at a time in a Fisher Shaking Water Bath model 127 at 35.0 ± 0.5°C (Evans *et al.* 2001; Packham 2006). The cells were agitated at an average horizontal shaking speed of 70 ± 5 cycles per minute, with traveling distance of 10.24 cm per cycle. All gloves were challenged for 2 hours. The four glove types were challenged by each of the six MWFs, and one blank glove for each glove type was also used. The one blank for each glove type served as the negative control for all the other six gloves of the same type challenged by MWFs. There were thus 4 × 6 + 4 = 28 glove pieces tested for 2 hours, with seven measurements of each glove piece at randomly selected exposed spots to obtain the quoted intrarun precision. A second set of nitrile gloves was challenged for 8 hours because nitrile gloves were recommended by NIOSH (1998). The total challenge and blank gloves comprised 35 pieces (28 + 6 + 1 = 35).

Penetration was checked by visual inspection for accumulation of challenge MWFs in the collection chamber and on the inside surface of the glove. After challenge, the permeation cells were disassembled, and the outer surfaces

Table 2 Disposable gloves used in this study

Glove type (color)	Descriptive brand name	Manufacturer (address)	Monomer
Nitrile (blue)	Kimberly-Clark Safeskin Blue Nitrile exam gloves (nitrile powder-free latex-free)	Kimberly-Clark (Roswell, GA)	Acrylonitrile/ butadiene
Latex (tan)	Kimberly-Clark Safeskin Satin Plus powder-free latex exam gloves	Kimberly-Clark (Roswell, GA)	*cis*-Isoprene
Chloroprene (blue)	SemperCare CRX by Sempermed chloroprene examination gloves (latex-free powder-free beaded)	Sempermed (Clearwater, FL)	Chloroprene
Vinyl (white)	OAK Laboratory Handies Standard Weight vinyl gloves (nonallergenic latex-free powder-free recyclable single use)	Oak (Stow, OH)	Vinyl chloride

of glove pieces were blotted dry with five pieces of Kimwipes. The glove pieces were re-conditioned in the desiccator for 24 hours before thickness measurements.

Thickness Measurements

Immediately before challenges, and after postchallenge reconditioning, the thickness of gloves was measured by a calibrated Marathon Electronic Digital Micrometer Model CO 030025 (0–25 mm, 0.001-mm resolution) (Fisher Scientific). Thickness at seven randomly selected spots on the glove piece was measured to give the average and variation of glove thickness. Color changes and other visual changes of the glove were also observed.

Statistics

Because the measurement sites for thickness before challenge did not affect the choices of measurement spots after the challenge, the two sets of thickness data were regarded as independent. An independent Student *t*-test was performed for the two sets of thickness data for each glove. The differences were considered statistically significant when $p \leq 0.05$. In addition, the data from each glove/MWF combination and its corresponding control were tested with two-way analysis of variance (ANOVA). ANOVA estimated the effects of the initial glove thickness (thickness for the blank versus that for the challenged gloves), the exposure (thickness before challenge versus that after the challenge), and the interactive effects of the above two factors. The thickness changes were significant when $p \leq 0.05$ for the exposure effects and/or for the interactive effects.

Results and Discussion

Thickness Changes Due to MWF Challenge

The glove thicknesses and their changes due to the six MWFs are summarized in Table 3.

The control gloves that went through the process without MWF challenge did not change their thickness significantly. All four control gloves had *p* values larger than 0.05 with the *t*-test). This assured that the possible thickness changes of gloves during MWF challenge was caused by MWFs, not by the ambient environment or by the measurement protocols.

After being exposed to STO for 2 hours, chloroprene swelled about 7.6%, and latex 36%. Both changes were significant with the *t*-test and ANOVA. These two gloves were not compatible with STO. Nitrile and vinyl gloves did not change their thickness.

After being challenged by the soluble oil SO1, latex swelled 39%, while vinyl shrank 9.3%. Both changes were significant with the *t*-test and ANOVA. The shrinkage of vinyl was probably due to the extraction of its additives/fillers by SO1. Gas chromatography–mass spectrometry analyses indicated large amounts of plasticizer phthalates present in a hexane collection solvent after contacting vinyl, although the specific phthalates and the amounts extracted from the glove were not determined (Xu and Que Hee 2007). The thickness change of chloroprene was significant with the *t*-test and insignificant with ANOVA. The change was only 3.5%. After being challenged by SO2, chloroprene swelled 6.5%, and latex swelled 12%. These two changes were statistically significant by both tests. The thickness of vinyl did not change significantly. Nitrile swelled 3.5%, which was significant with the *t*-test, but insignificant with ANOVA.

For the semisynthetic SES, chloroprene, latex, and vinyl did not change thickness significantly. Nitrile swelled only 2.5%, which was statistically significant with *t*-tests, but not with ANOVA.

For synthetic MWF SY1, no glove thickness changed significantly. For SY2, nitrile swelled only 3.2%, which was significant with the *t*-test, but not with ANOVA.

The polar constituents/additives in these MWFs with up to 85% of mineral oil might induce these changes, as nitrile and vinyl were not affected by straight oil MWF, which is nearly 100% mineral oil (Xu and Que Hee 2006a). Overall, nitrile and vinyl were the better two candidates for soluble oil MWFs. This is the first time that thickness change data have been generated for gloves and MWFs.

Table 3 Glove thickness changes due to metalworking fluids challenge for 2 hours[a]

Challenge	Glove	l_b [b]	l_a [c]	% Δl [d]
Control	Chloroprene	159.0 ± 10.4	162.7 ± 8.6	2.3 ± 5.5
	Latex	131.4 ± 1.4	129.3 ± 2.7	−1.6 ± 2.4
	Nitrile	121.0 ± 2.6	121.9 ± 2.4	0.7 ± 2.4
	Vinyl	155.6 ± 2.6	156.4 ± 3.3	0.6 ± 3.2
STO	Chloroprene	149.4 ± 3.3	160.7 ± 3.7[e,f]	7.6 ± 2.6
	Latex	128.1 ± 1.6	174.0 ± 2.5[e,f]	35.8 ± 2.1
	Nitrile	116.3 ± 2.6	118.8 ± 3.0	2.1 ± 4.0
	Vinyl	142.6 ± 3.9	145.6 ± 2.4	2.1 ± 3.6
SO1	Chloroprene	152.9 ± 5.1	158.1 ± 3.7[e]	3.5 ± 4.6
	Latex	121.3 ± 4.3	168.4 ± 10.0[e,f]	38.9 ± 7.8
	Nitrile	115.9 ± 3.5	118.6 ± 3.3	2.3 ± 2.7
	Vinyl	195.7 ± 8.3	177.4 ± 18.4[e,f]	−9.3 ± 8.8
SO2	Chloroprene	133.6 ± 3.0	142.3 ± 3.6[e,f]	6.5 ± 3.8
	Latex	121.4 ± 1.7	135.9 ± 5.8[e,f]	11.9 ± 5.7
	Nitrile	114.3 ± 1.7	118.3 ± 1.9[e]	3.5 ± 3.0
	Vinyl	142.3 ± 2.8	143.7 ± 1.9	1 .0 ± 1.6
SES	Chloroprene	155.3 ± 3.3	153.7 ± 3.5	−1.0 ± 1.2
	Latex	120.6 ± 3.3	123.4 ± 2.8	2.4 ± 3.7
	Nitrile	115.3 ± 1.3	118.1 ± 2.0[e]	2.5 ± 1.4
	Vinyl	169.0 ± 5.4	172.3 ± 10.6	1.9 ± 7.5
SY1	Chloroprene	159.4 ± 5.4	159.3 ± 5.1	−0.1 ± 6.0
	Latex	137.7 ± 3.4	136.4 ± 4.9	−0.9 ± 4.0
	Nitrile	123.1 ± 2.3	124.4 ± 1.7	1 .0 ± 2.4
	Vinyl	169.3 ± 6.1	174.6 ± 6.8	3.1 ± 5.2
SY2	Chloroprene	158.4 ± 5.4	156.6 ± 3.3	−1.2 ± 3.0
	Latex	137.9 ± 5.4	137.7 ± 3.1	−0.1 ± 4.6
	Nitrile	115.6 ± 1.3	119.3 ± 2.2[e]	3.2 ± 1.1
	Vinyl	151.3 ± 4.6	150.7 ± 8.7	−0.4 ± 7.3

[a] In this table, the standard deviation follows the symbol ±

[b] l_b is thickness (μm) of glove before the challenge

[c] l_a is thickness (μm) of glove after the challenge

[d] Percentage of thickness change, with the minus sign signifying shrinking

[e] The thickness change is significant with the independent Student *t*-test

[f] The thickness change is significant with analysis of variance

The similar performance of latex and chloroprene may be explained by their similar backbone structure (Xiao *et al.* 1997; Mellstrom and Boman 2005). Both polymers have backbone structural units consisting of four carbon atoms. Within the unit, both have a double carbon bond between two carbon–carbon sigma bonds. Carbon–carbon sigma bonds connect the structural units. The improved performance of chloroprene relative to latex may arise from the presence of the chlorine atom in the side chain to withdraw electron density from the double bond to make it more inert, while latex has only carbon and hydrogen in its side chains. Nitrile, as a copolymer, has two different structural units, one with four atoms and one with single-bonded two atoms. It has the polar nitrile functional group (−CN) in its side chains. Vinyl has a backbone consisting of only a single bond, and chlorine (−Cl) in its side chains. The fewer double-bonds and more electron withdrawing side-chains may explain better glove performance against high oil-content MWFs. Electron-donating functional groups like alkyl groups might be expected to make any double bonds more reactive. Cross-link type and cross-link density in glove materials may also affect the swelling as shown for styrene-butadiene rubber (George *et al.* 1999). Because the straight oil used here (Table 1) had mostly alicyclic saturated and unsaturated hydrocarbons, it is quite nonpolar. While both soluble oils contained the naphthenic distillate fraction, they also contained polar additives to promote water solubility. Thus, the overall polarity of the soluble MWFs was moderately polar. The semisynthetic MWF also contained the naphthenic distillate but also a higher proportion of petroleum sulfonic acid sodium salt to make the solution more polar than the soluble oil MWFs. The synthetic MWFs, being water soluble, are quite polar, and have polar additives too.

Color and Other Changes

No MWFs were visible in the collection chambers of the ASTM cell or on the inner surface of any tested glove, showing that no visible penetration or permeation occurred.

The color of the chloroprene glove outer surface changed from blue to yellowish blue after STO challenge, but remained unchanged after exposure to other MWFs. The latex glove outer surface became darker after STO exposure, and became lighter/whiter after SO1 exposure. Their color did not change after exposure to other MWFs. The color of the nitrile glove outer surface remained unchanged after STO challenge, but changed from blue to yellowish blue for other MWFs, with SY1 and SO1 producing the most changes. The color of the vinyl glove outer surface showed no obvious changes for the six MWFs. Glove color changes could be due to the adsorption of the MWF on the glove, the extraction of pigment from the glove by the MWFs, or the chemical reaction of the MWFs and the glove materials.

In addition to thickness increasing, the lateral dimension of chloroprene increased after SO1 and SO2 challenges. The contact area of latex also enlarged after STO, SO1, and SO2 challenges.

In addition to glove thickness, lateral dimension, color and other visual observations, other glove parameters such as puncture and tensile strength changes (Forsberg *et al.* 1986; Gao and Tomosovic 2005) after MWF challenges

Table 4 Nitrile thickness changes due to metalworking fluids challenge for 8 hours[a]

Challenge	l_b^b	l_a^c	% Δl [d]
Control	118.9 ± 3.2	121.6 ± 2.6	2.3 ± 3.8
STO	114.3 ± 3.3	116.1 ± 2.5	1.6 ± 4.8
SO1	122.7 ± 1.6	140.0 ± 2.3 [e f]	14.1 ± 2.1
SO2	116.9 ± 1.8	132.4 ± 2.1 [e f]	13.3 ± 2.1
SES	122.4 ± 2.6	127.0 ± 3.6 [e]	3.7 ± 3.3
SY1	119.0 ± 2.8	120.4 ± 1.4	1.2 ± 2.6
SY2	119.0 ± 2.4	123.4 ± 2.8 [e]	3.7 ± 3.6

[a] The symbols in this table have the same meaning as those defined for Table 3

should be performed in the future. Scanning electron microscopy may provide valuable information on the structural changes of gloves after MWF challenge (He *et al.* 2003). Thickness measurements, however, provided fast and inexpensive screening results for compatibility with the MWF. The field screening of gloves in the above manner is also much faster and less expensive than penetration and permeation testing. The question that still needs to be addressed in future research is how much change in thickness is necessary to stop using the glove in the field. Some answer to this question was then attempted with a longer exposure for a disposable nitrile glove, the nitrile glove in its chemically protective form being recommended by NIOSH for use against MWFs (NIOSH 1998).

The Changes of Nitrile Gloves After 8-Hour Challenges

With the average workday of 8 hours and a break after every 2 hours, a disposable glove will usually be discarded well before 8 hours. The aim here was to show the relationship of glove swelling with exposure duration. It was expected that the glove changes at 8 hours would be more measurable.

After being challenged for 8 hours, no visible penetration or permeation of MWFs occurred for the disposable nitrile gloves. The gloves swelled significantly for SO1, SO2, SES, and SY2 with *t*-test, and significantly for SO1 and SO2 with ANOVA (Table 4). Disposable nitrile did not maintain its original integrity up to 8 hours against soluble oil MWF (SO1 and SO2) by the *t*-test and ANOVA, and SES and SY2 by the *t*-test. The glove also swelled significantly at 2 hours for SO2, SES, and SY2 by the *t*-test. As expected, the relative swelling was higher at 8 hours relative to at 2 hours (6.4 times for SO1, 3.9 times for SO2, 1.4 times for SES, and 1.2 times for SY2 (Figure 1)). Thus, most MWFs, especially SO1 and SO2 but not STO or SY1, continued to be absorbed by the nitrile material, enlarging its volume, while the elastic retraction of the nitrile polymer backbones was less than the osmotic pressure driving the compounds into nitrile (Aithal and Aminabhavi 1991).

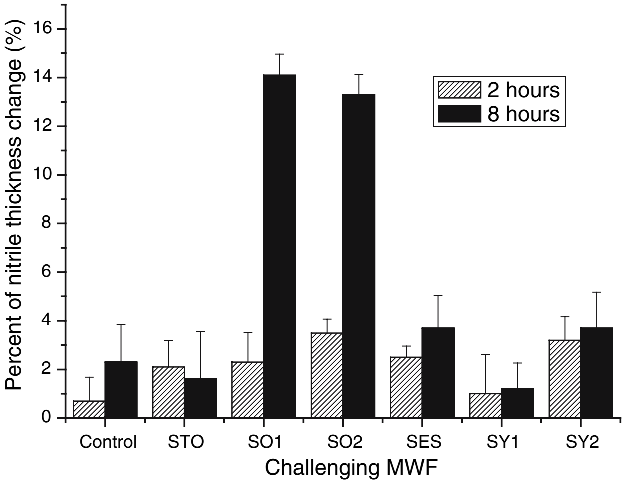

Fig. 1 Relative thickness change (with error bars) of nitrile gloves after 2 hours and 8 hours of metalworking fluids challenge

Glove changes due to some of the components in Table 1 have been studied using pure compounds. Ethanolamine was found to cause Viton glove materials to swell to such a degree that it was impossible to measure accurately (Evans and Hardy 2004). Infra-red spectroscopy revealed that one ethanolamine molecule combined with three nitrile (–CN) groups in butadiene nitrile rubber (Gulimov and Shmurak 1969). Swelling of ethylene-propylene-diene terpolymer polymer by ethanolamine (Nielsen and Hansen 2005) and solubility of triethanolamine in unvulcanized rubbers have also been studied (Sarbach and Garvey 1947). Glove swelling for other components listed in Table 1 were not found in the peer-reviewed literature.

Some glove manufacturers provide permeation data and subjective degradation ratings in their chemical resistance guides. Kimberly-Clark provides normalized and actual breakthrough time data for three types of disposable nitrile gloves, but not against any chemicals in Table 1 (Kimberly-Clark Corporation 2001). For these chemicals, no performance data were found for other disposable gloves either. The guide for the thicker Ansell chemically protective gloves (Ansell 2003) had only ethanolamine and triethanolamine, which are also listed in Table 1. The degradation rating of chemically protective nitrile, neoprene (similar to chloroprene), vinyl, and natural rubber (similar to latex) gloves were all excellent or good for the two compounds. In the present study, only nitrile swelled significantly for SY2, which had both alkanolamines and acids.

No degradation ratings are available in the Ansell guide for mineral oils used in the MWFs. Nitrile and neoprene had excellent rating for lower boiling point fractions of petroleum distillates: Stoddard solvent, naphtha VM&P, and kerosene. Vinyl had a fair rating for these three distillates; and natural rubber (latex) was not recommended for any of the distillates. In the present study, chloroprene was found to swell after challenges by mineral-oil-based MWFs, indicating the effects of other additives in MWFs.

Penetration/permeation data obtained in ASTM permeation cell experiments need to be obtained to answer the question on what degree of swelling or shrinking should be used to identify the disposable gloves that should not be used in the field. We have answered this question partially for the straight oil and four of the glove types used in the present study (Xu and Que Hee 2007). The average permeated masses after 8 hours for perfluorohexane collection solvent in μg/cm^2 corrected for mass of glove additives were: chloroprene 2000 ± 240, 6600 ± 140, 20 ± 40, and 140 ± 40. These data are consistent with the use of thickness changes of disposable gloves challenged by straight oil MWFs after 2 hours.

Conclusions

This paper is the first to study systematically the performance of four types of gloves against all of the four major types of MWFs relative to thickness changes as a screening method for single gloves. The measurement is fast and easy compared with the difficult MWF chemical analysis. In summary for the 2-hour exposure data, chloroprene swelled significantly after exposure to STO and SO2. Latex swelled significantly for STO, SO1, and SO2. Chloroprene and latex were unaffected by exposure to low-oil-content semisynthetic and synthetic MWFs. Nitrile swelled less than 5% for SO2 and SY2 (significant with the *t*-test and nonsignificant with ANOVA). The thicker chemically protective nitrile gloves were recommended by NIOSH (1998) for all types of MWFs. In previous work, the disposable nitrile glove exhibited negligible swelling and minimal permeation for the straight oil MWF (Xu and Que Hee 2006b). Shrinking was statistically significant for SO1. Vinyl was compatible for MWFs other than the soluble oil type. This glove material has not been evaluated against MWFs in the literature.

The utility of glove swelling in determining the exact duration of use of a glove or in assessing risk may be limited. Degradation and permeation data are more relevant for such purposes. However, degradation and permeation testing require much more time and equipment, and for complex mixtures like MWFs, the challenge of chemical analysis is immense. For such complex challenges, glove swelling can be used as a screening method for gloves to predict degradation. Further studies on the correlation of permeation and glove swelling need to be conducted.

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