

# Aqueous Reactive PU Prepolymer Containing Sulfoisophthalate Sodium for Hydrophilic Finishing and Antistatic Finishing of Poly(ethylene terephthalate) Fabrics

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**ABSTRACT:** In the study, we allowed PEG and dimethyl 5-sulfoisophthalate sodium salt (SIP) to undergo transesterification to obtain PEG containing sulfonic groups (SE), then used SE and isophorone diisocyanate as soft and hard chains, respectively, and methyl ethyl ketoxime, hydroxyethyl methacrylate or 2,3-Epoxy-1-propanol as blocking reagents to synthesize three kinds of reactive urethane oligomers (MSE, HSE, and OSE). PET textiles treated by oligomers were investigated for their effects to the durable hydrophilic properties of PET fibers under different processing temperatures, time lengths, and oligomer concentrations. The results are concluded and described later: The add-on and durability of processed fabrics both were improved following the rise of processing temperature and a longer processing time. When oligomer concentration was increased, the add-on on processed textiles also increased, but their durability decreased. When PEG segment was larger, the add-on and durability both decreased. The hydrophilicity of processed textiles was proportional to the

increase of oligomer concentration. The processing time was more crucial to the hydrophilic property of HSE processed textiles, but for that of MSE, the processing temperature was more important. The hydrophilic property of OSE processed textiles absolutely depended on the add-on of processed textiles. Textiles processed in oligomers of PEG molecular weight 1000 showed the highest vertical wicking height. Within these three kinds of oligomers, MSE led to the highest add-on on processed textiles and HSE textiles possessed the best of durability. OSE processed textiles possessed the best hydrophilic efficiency and electrostatic dissipating property. Textiles processed in HSE containing PEG molecular weight 1000 could have the best hydrophilic and durability. © 2007 Wiley Periodicals, Inc. *J Appl Polym Sci* 106: 599–610, 2007

**Key words:** reactive urethane oligomer; poly (ethylene terephthalate) (PET) fiber; hydrophilic finishing; antistatic finishing; dimethyl 5-sulfoisophthalate sodium salt

## INTRODUCTION

Polyethylene terephthalate fibers, which have excellent tensile strength, wear-resistance, heat-resistance, and weather proof property, are widely applied in the textile and industry. However, because of the lack of hydrophilic functional groups, this kind of fibers also has some disadvantages such as that the fibers are difficult to absorb moisture, and are likely to have static electricity, soiling, and sultry feeling while wearing the textile. Therefore, the antistatic finishing and hydrophilic finishing of PET fibers became necessary. The methods used to improve PET fibers' hydrophilic property principally include copolymerization of hydrophilic monomers,<sup>1</sup> combination of hydrophilic ingredients and spinning,<sup>2</sup> grafting

copolymerization of hydrophilic monomers,<sup>3</sup> cavitation erosion or hollowing of fiber, and fluffing of textile,<sup>4</sup> as well as covering of hydrophilic resin or adsorption.<sup>5–8</sup> Regarding the antistatic finishing, static electricity on textiles can be reduced by enhancing the hydrophilic property of textiles, and alternatively using smoothening reagents, softeners, cationic surfactants, or cationic resins to process textiles to reduce the friction of fibers or neutralize the ionic property. Resistance to static electricity thus can be achieved.<sup>9–13</sup> Researches about antistatic finishing and hydrophilic finishing of PET textiles mostly came from patent reports. Lark and Charles<sup>5,6</sup> used a series of anhydride and polyethylene glycol to conduct transesterification, and the obtained hydrophilic ester compounds could improve the properties of PET processed textiles, which are hydrophilic, soil-resistant, and antistatic. Singer et al.<sup>8</sup> used various kinds of acrylate containing stearic acid to improve hydrophilic property and softness of processed textiles. Schwartz<sup>9</sup> synthesized an antistatic rinse from several kinds of acrylic acid and PEG, and the rinse mixed softener can

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improve the antistatic property and softness of textiles when they are rinsed at room temperature. Furthermore, Lin and Chen<sup>10</sup> used soft chains, hard chains, and *N*-methyldiethanolamine to synthesize cationic urethane oligomers, and studied its hydrophilicity, crystallinity, and antistatic properties. They found out that the membrane formed from the urethane oligomers has lower static electricity. Covering with hydrophilic resins can improve hydrophilic property of textiles greatly, but the washing durability remained to be improved further. Thus, the application of reactive reagents has been considered gradually<sup>14</sup>.

In the past, reactive urethane oligomers were applied widely in adhesives and paints, and the formative products have excellent wear-resistance, weatherproof property, elasticity, and peel bond strength etc.<sup>11–18</sup> Reactive groups include isocyanate type which is used to block NCO functional groups at end terminals of prepolymer,<sup>14–18</sup> acrylic type whose end terminals contain ethylene groups,<sup>19–21</sup> and epoxy type containing epoxide groups.<sup>22–24</sup> In particular, as considering environmental protection, waterborne products have drawn much attention in past few years.<sup>25–32</sup> In researches on adhesives, isocyanate type included cationic<sup>25</sup> and anionic<sup>26</sup> PU prepolymers. In acrylic type, different kinds of acrylate,<sup>28</sup> neutralizers, and diluent<sup>30</sup> were studied. In terms of epoxy type, there were researches, which synthesized waterborne epoxy-urethane, in combination with epoxy resins<sup>31</sup> or allyl novolac resin.<sup>32</sup> In the past, anionic waterborne PU mostly used dimethylolpropionic acid as an ionic group, but recently sulfonic groups have been incorporated in anionic waterborne PUs. According to previous researches, general anionic waterborne PUs containing sulfonic groups, compared to those containing carboxyl groups, have more even emulsion with tiny particle. Furthermore, surface tension of the solution is lower, and since this type of PUs has small phase separation, the thin membrane formed has a larger tensile strength.<sup>33,34</sup> Our laboratory has also studied the solution properties and the thermal properties of end products of aqueous urethane oligomers, containing different reactive groups and sulfonic groups. It was found out that the urethane oligomers, whose NCO group is blocked with MEKO (isocyanate type), have the largest particle size of dispersing solution, particle distribution degree, and streaming current reading. Those which contain epoxide groups (epoxy type), however, have a larger surface tension and contact angle while the properties of those containing HEMA (acrylic type) fall in the range between the first two described previously. Considering the excellent properties of urethane oligomers containing sulfonic groups, this research applied the compounds of different reactive groups described earlier to hydrophilic finishing of PET textiles, and

conferred the durable antistatic property and hydrophilic property of treated fabric.

We allowed PEG of different molecular weights and dimethyl 5-sulfoisophthalate sodium salt (SIP) to undergo transesterification to obtain PEG (SE) containing sulfonic groups, and used SE and isophorone diisocyanate (IPDI) as soft and hard chains, respectively, and methyl ethyl ketoxime (MEKO), hydroxyethyl methacrylate (HEMA), or glycidol (EPO) as blocking reagents to synthesize three kinds of reactive urethane oligomers. The synthesized oligomers were used to treat PET fabrics by pad-dry-cure process. PET textiles treated by oligomers, which have different PEG molecular weights and reactive functional groups, were then investigated for their effects to the add-on and hydrophilic properties of PET fibers under different processing temperatures, time lengths, and oligomer concentrations.

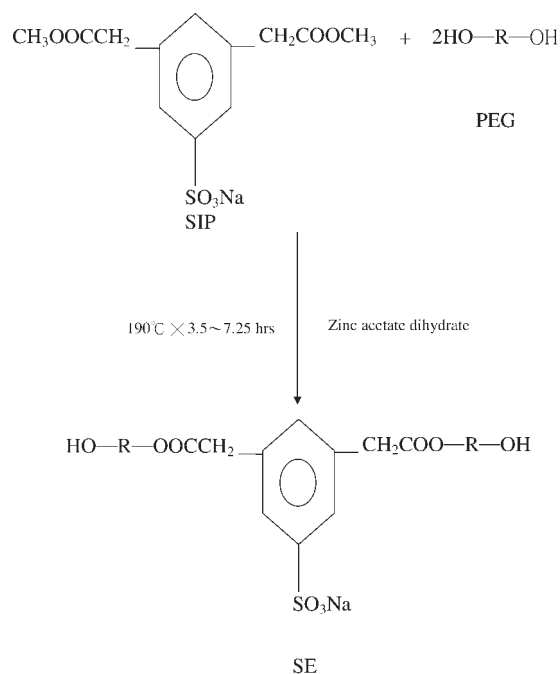
## EXPERIMENTAL METHOD

### Preparation of sulfonated diol

To synthesize urethane oligomer, first, sulfonated diol was synthesized according to the method of Wei and Yu.<sup>35</sup> One mole of dimethyl 5-sulfoisophthalate sodium salt (SIP, GR grade, ACROS) and 2 moles of ethylene glycol (EG, GR grade, ACROS) or Polyethylene glycol (PEG, molecular weight 400, 1000, 2000, 3000, GR grade, ACROS) were mixed and dehydrated in vacuum. Zinc acetate dehydrate (GR grade, ACROS) as the catalyst was subsequently added and incubated with ambient nitrogen gas at 190°C for 3.5–7.25 h for transesterification to produce sulfonated diols (SE). The synthesized products were confirmed by titration of OH, GPC, and FTIR analysis. The reaction equation is shown in Scheme 1, and the composition of the synthesized products and code names are listed in Table I.

### Synthesis of urethane oligomer

To synthesize the aqueous reactive urethane oligomer, 1 mole of sulfonated diol (SE) as soft chain was dissolved in *N,N*-dimethylformamide (DMF) and dehydrated in a vacuum, and reacted with 2 moles of Isophorone Diisocyanate (IPDI, GR grade, ALDRICH) with dibutyltin dilaurate (DBTDL, GR grade, ALDRICH) as a catalyst under ambient nitrogen gas at 45°C for 2–3.5 h. The temperature was subsequently increased to 60°C and 2 moles of methyl ethyl ketoxime (MEKO, GR grade, ACROS) or hydroxyethyl methacrylate (HEMA, GR grade, ACROS) or 2,3-Epoxy-1-propanol (EPO, glycidol, GR grade, ACROS) was added for 60 min to proceed NCO blocking, followed by cooling in a water bath for 15 min. The emulsified dispersion of three kinds of



R: PEG ( $\bar{M}_n$ =62, 400, 1000, 2000, 3000)

**Scheme 1** The synthesis of sulfonated diols.

waterborne urethane polymers containing different reactive terminals (MSE, HSE, and OSE) were obtained by adding water. The synthesized products were confirmed by titration of NCO, GPC, and FTIR analysis. The reaction equation is shown in Scheme 2, and the composition and the symbols of the synthesized products are displayed in Table I.

### Analysis of structure

FTIR spectra was taken by BIO-RED system within the scanning range of 400–4000 nm for 16 times at 25°C. The NCO titration and hydroxyl number analysis were performed according to the methods of David<sup>36</sup> and potassium hydroxide, respectively. Gel permeation chromatography (GPC) test using the polystyrene as a standard and the sample at a concentration of 7–8 mg/mL was tested by Water RI-6000 system at a speed of 1 mL/min.

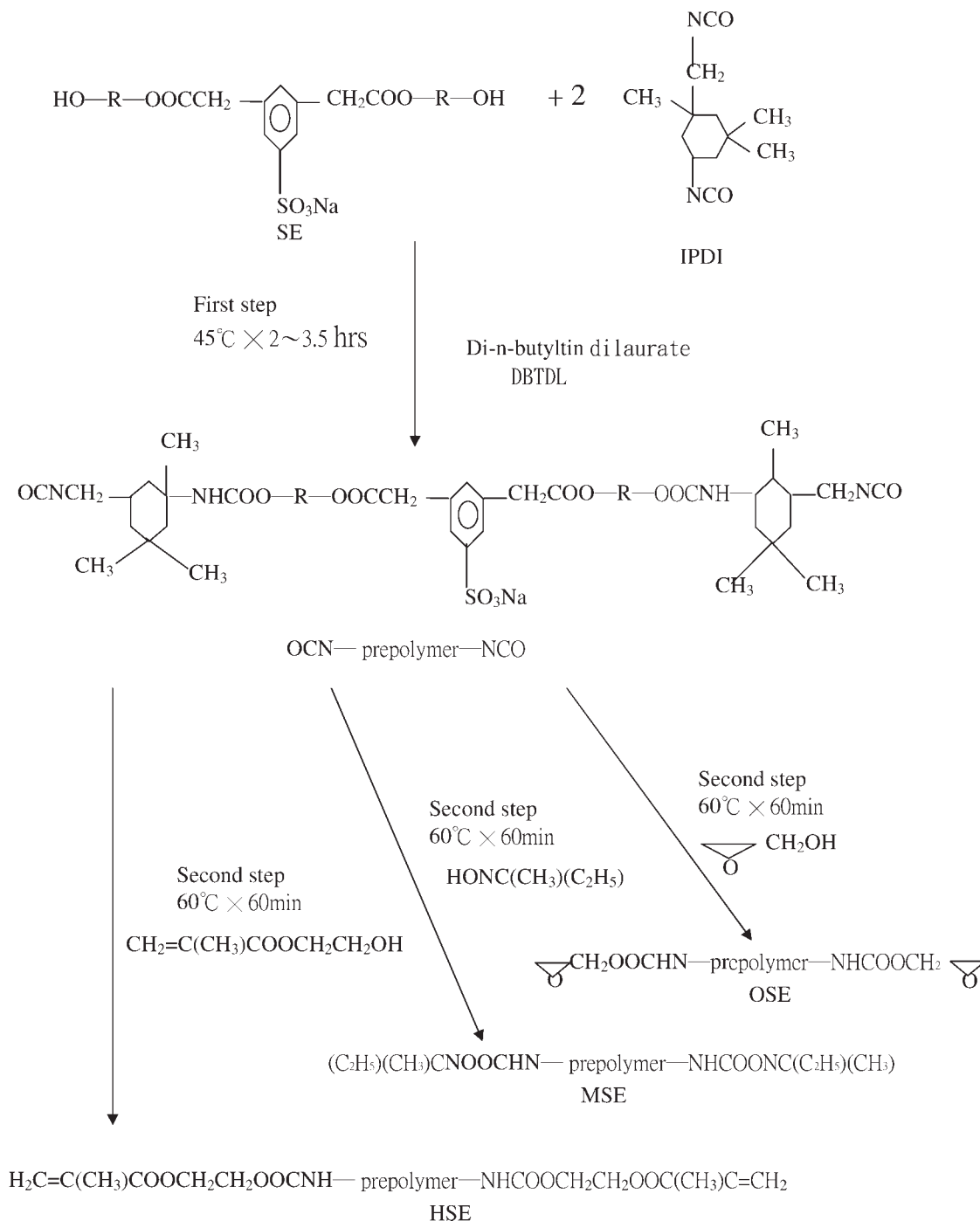
### Process of fabrics finishing

The PET fabrics were treated by Pad-Dry-Cure process. The treated solution constituted of oligomer and cosolvent of water and *N,N*-dimethylformamide (DMF). In the case of the HSE solution, benzoyl peroxide (BPO 1% of oligomer weight) was added as the initiator, and in the MSE type, CAT32 (0.05% of

**TABLE I**  
The Compositions and Molecular Weights of Synthesized Sulfonated Diols and Oligomers

Synthetic type	Symbol	Composition (wt %)							Molecular weight	
		Soft segment (SE)			Hard segment	Reactive group			Theo.	Exp.
		SIP	PEG			IPDI	HEMA	MEKO		
			$\bar{M}_n$	Ratio						
Sulfonated diol	SE62	74.4	62	25.6	0	0	0	0	422	438
	SE400	25.5	400	74.5	0	0	0	0	1112	1146
	SE1000	11.8	1000	88.2	0	0	0	0	2380	2430
	SE2000	6.2	2000	93.8	0	0	0	0	4789	4860
	SE3000	4.2	3000	95.8	0	0	0	0	6802	6920
Acrylic type urethane oligomer	HSE62	24.8	62	8.6	42.0	24.6	0	0	1060	1152
	HSE400	15.1	400	44.3	25.6	15.0	0	0	1736	1892
	HSE1000	8.9	1000	67.1	15.1	8.9	0	0	2936	3220
	HSE2000	5.3	2000	80.4	9.0	5.3	0	0	4936	5140
	HSE3000	3.8	3000	86.0	6.4	3.8	0	0	6936	7130
Isocyanate type urethane oligomer	MSE62	27.0	62	9.3	45.8	0	17.9	0	974	1082
	MSE400	15.9	400	46.5	27.0	0	10.6	0	1650	1703
	MSE1000	9.2	1000	69.1	15.6	0	6.1	0	2850	3030
	MSE2000	5.4	2,000	81.9	9.1	0	3.6	0	4850	5020
	MSE3000	3.8	3000	87.2	6.5	0	2.5	0	6850	7020
Epoxy type urethane oligomer	OSE62	27.8	62	9.5	47.0	0	0	15.7	592	612
	OSE400	16.2	400	47.3	27.4	0	0	9.1	1624	1720
	OSE1000	9.3	1000	69.8	15.7	0	0	5.2	2824	2920
	OSE2000	5.4	2000	82.3	9.2	0	0	3.1	4824	5030
	OSE3000	3.8	3000	87.5	6.5	0	0	2.2	6824	6920

S, E, and number in symbol represent SIP, PEG, and molecular weight of PEG respectively. HSE, MSE, and OSE in symbol represent acrylic type, isocyanate type, and epoxy type, respectively. Exp, experiment; Reac, reactant; Prod, product; Theo, theory.



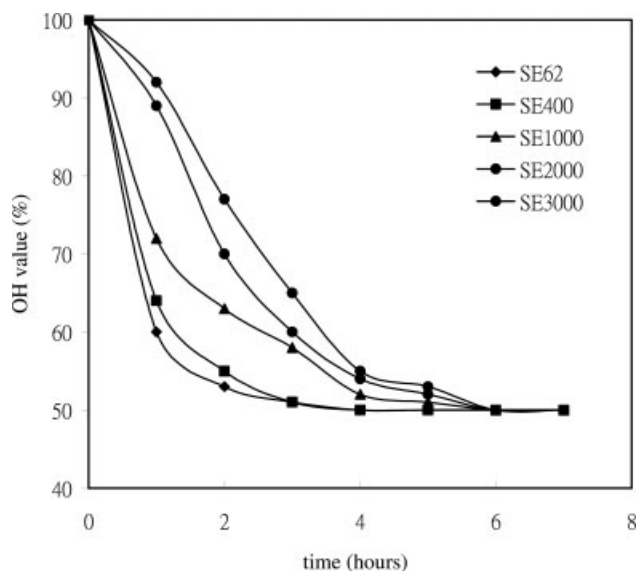
**Scheme 2** The synthesis of reactive urethane oligomers.

oligomer) was added as the catalyst of finishing. PET fabric (Everest, Taiwan) for finishing was processed by weight reduction with NaOH, and the reduction ratio was 12 wt %. For the Pad-Dry-Cure process, padding of PET fabric (was carried out by the one-dip-one-nip (pick up as 85%), predrying at 80°C for 5 min and curing at 120–210°C for 30–300 s. Then the treated fabric was washed by a sodium carbonate solution of 2 g/L at 60°C for 20 min. The add-on and

physical properties of treated fabric were tested as follows.

#### Properties of finished fabrics

The washing durability was tested by AATCC 135. The regain, time of drop absorption, vertical wicking height, and half-life were evaluated by the ASTM 629-88, CNS12915 water absorption A method (the



**Figure 1** The residual ratio of OH value of PEG synthesized by SIP for sulfonated diols under different reaction time of transesterification.

drop-down standard), CNS12915 water absorption B (Byreck standard), and JIS-L1094 A. The bending length and tensile strength were measured by CNS12915 (stiffness 45° Cantilever) and ASTM D1682-64 (1975).

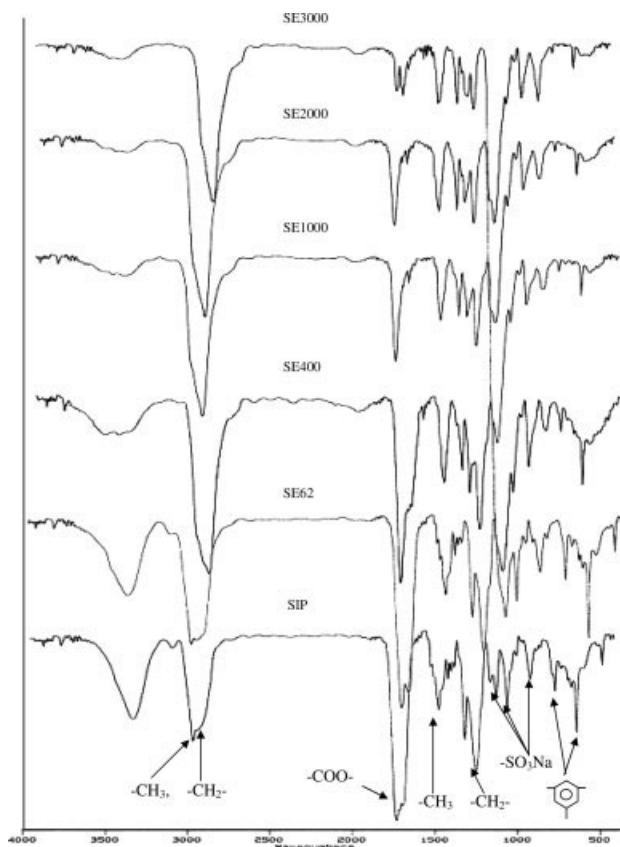
## RESULTS AND DISCUSSION

### Synthesis and identification

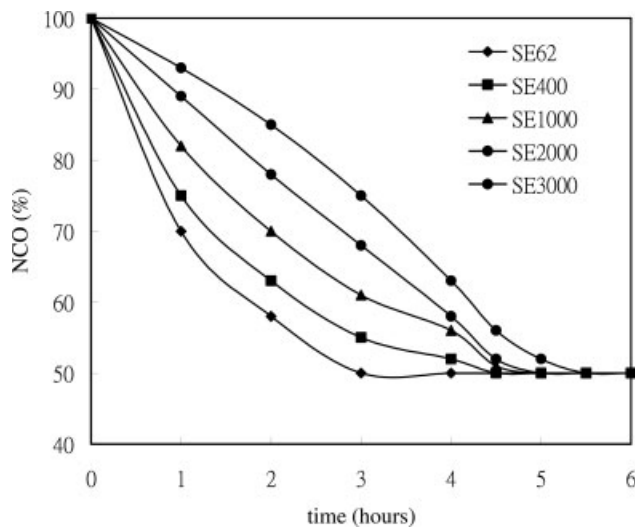
At the aspect of PEG soft chain containing sulfonic acid group (sulfonated diol; SE), the SIP was allowed to transesterification with PEG of different molecular weights, and the residual OH value versus reaction time is depicted in Figure 1. The transesterification of SIP to glycols is at 190°C (from room temperature to 190°C it is in the speed of 10°C per minute) with zinc acetate dehydrate as a catalyst. While the residual OH value reached one half of the reactants, it indicates the completion of transesterification. From the diagram, the necessary reaction time increased as the increase of PEG molecular weight, namely that the PEG of molecular weight 62 requires 3.5 h to finish the reaction and the PEG of molecular weight 3000 requires 7.5 h. The FTIR spectrum of sulfonated diol in Figure 2 shows that the raw material SIP possessed absorbance peaks of tri-substituted benzyl ring at 700, 850, and 1480  $\text{cm}^{-1}$ . The absorptions of sulfonic acid group appeared at 1220, 1040, and 980  $\text{cm}^{-1}$ . After the SIPM transesterification with PEG to eliminate methanol,  $-\text{CH}_3$  of SIPM absorption at 1450  $\text{cm}^{-1}$  disappeared, and absorption peak of ester group at 1740  $\text{cm}^{-1}$  shifted to the right side because more H-bonding were produced between the  $-\text{COO}-$  and ethylene oxide (EO) of SE. However, the absorption

areas of  $-\text{O}-$  at 1112  $\text{cm}^{-1}$  and  $-\text{CH}_2-$  at 3000  $\text{cm}^{-1}$  from the amount of EO increased when the PEG molecular weight of sulfonated diol increased, but all the absorption areas of OH group, ester group, phenyl group, and sulfonic group declined.

Urethane oligomer was first synthesized by prepolymerizing IPDI, which was introduced to the end of SE, and then the end of prepolymer was blocked by the HEMA. Figure 3 shows the results of NCO analysis of urethane oligomer. The IPDI reacts with sulfonated diol (SE) at 45°C. (from room temperature to 45°C it is in the speed of 1°C per minute) with DBTDL as a catalyst. The residual NCO value reached one half of the reactants indicating the completion of prepolymerization. The sulfonated diol containing larger PEG length required a longer reaction time to react with the hard segment IPDI, and the reaction of all kinds of oligomer completed within ~2–3.5 h. Figure 4 shows the FTIR spectra of urethane oligomers. Without regarding the kinds of urethane oligomer, the absorptions of  $-\text{NH}-$  at 3400  $\text{cm}^{-1}$ ,  $-\text{C}-\text{N}-$  at 1532 and 1226  $\text{cm}^{-1}$ , and  $-\text{COO}$  at 1740  $\text{cm}^{-1}$  all revealed the formation of urethane group. In addition to this, different reactive functional groups could be seen from the spectrum, the HSE oligomer had an absorption peak of  $-\text{C}=\text{C}-$  at 1650 and 1430  $\text{cm}^{-1}$ , and the MSE oligomer had the a  $-\text{C}-\text{N}-$  absorp-

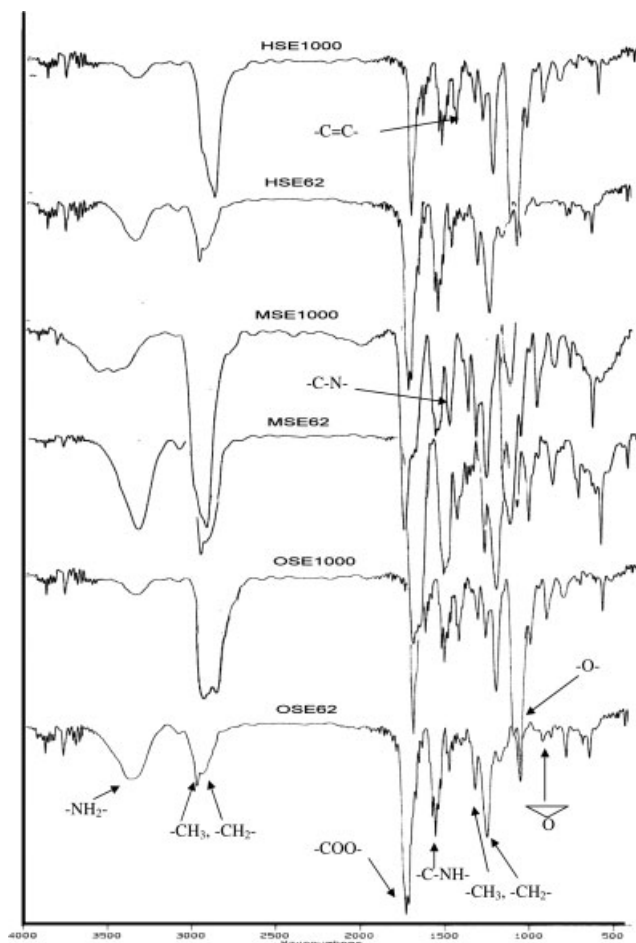


**Figure 2** The IR spectra of sulfonated diols.



**Figure 3** The residual ratio of NCO value of IPDI synthesized with sulfonated diols for the oligomer under different reaction time of first step.

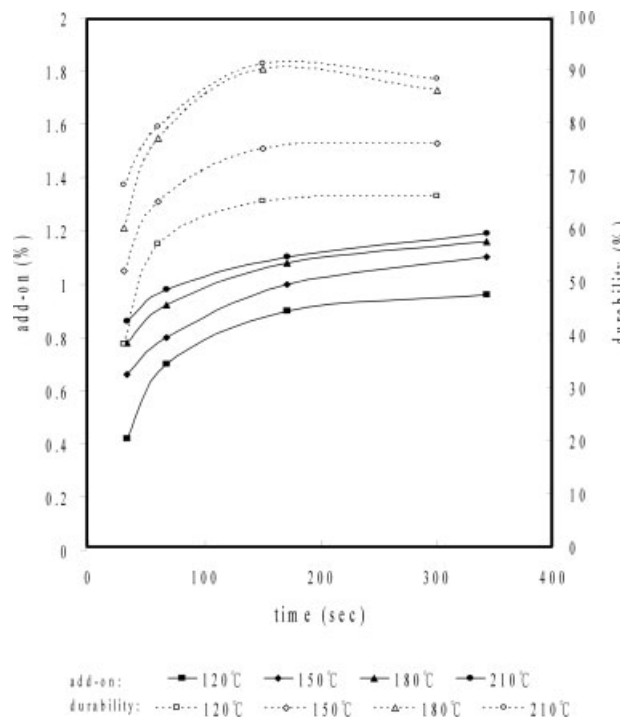
tion peak at  $1650\text{ cm}^{-1}$ . The epoxide group of OSE oligomer had absorption peaks at  $800$  and  $1250\text{ cm}^{-1}$ . Therefore, the structure of oligomer could be confirmed.



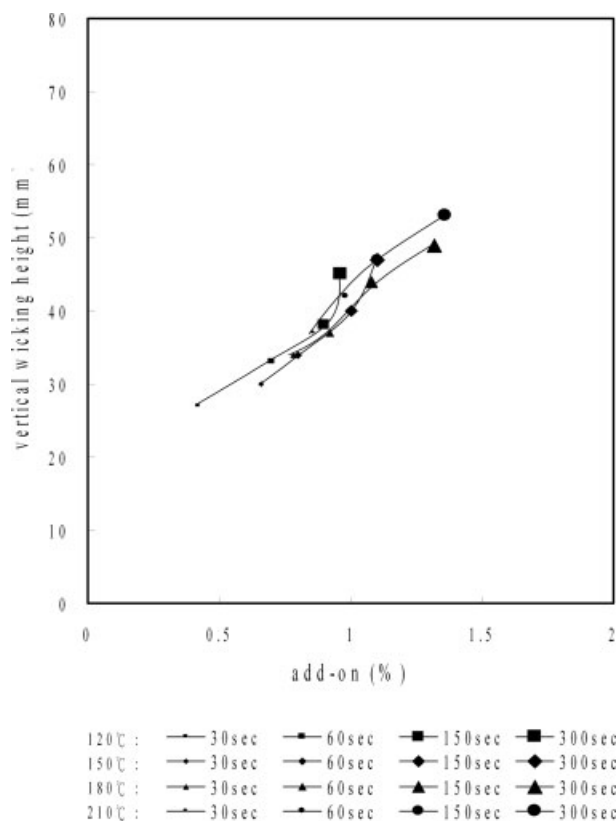
**Figure 4** The FTIR spectra of urethane oligomers.

### Durable hydrophilic finishing of PET fabric treated by urethane oligomers of acrylic type

Figure 5 shows the add-on and durability of PET fabrics treated in 2% HSE1000 oligomers at different temperatures and lengths of time. Both add-on and durability were improved following the increase of processing temperature, in particular at the temperatures higher than  $180^\circ\text{C}$ , and the add-on of processed textiles was increased more significantly. Besides, while processing time extended longer, add-on and durability both increased slowly, however, increase of add-on gradually slowed down after 150 s although durability dropped down. Since the HSE type of urethane oligomers uses BPO as an initiator, according to previous researches, in the presence of BPO initiator at  $120^\circ\text{C}$ , ethylene groups at the ends of oligomers can undergo an addition reaction, and tangle with and attach onto fibers.<sup>8</sup> In addition, when temperature exceeds  $150^\circ\text{C}$ , ethylene groups can also graft to PET fibers,<sup>3</sup> and simultaneously react with  $-\text{CH}_2-$  of ethylene oxide (EO) in the oligomers.<sup>37,38</sup> Hence, add-on and durability increased following the rise of temperature. At temperatures above  $180^\circ\text{C}$ , the motion in PET amorphous region is better that can allow chemical reagents to be internalized, and give a greater durability. At a high temperature and after 150 s processing, the increase of add-on slowed down, and durability declined slightly, which may be due to the pyrolysis of some oligomers.



**Figure 5** The add-on and durability of fabrics treated by HSE1000 oligomer under various curing time and temperature.



**Figure 6** The vertical wicking height and add-on of fabrics treated by HSE1000 oligomer under various curing time and temperature.

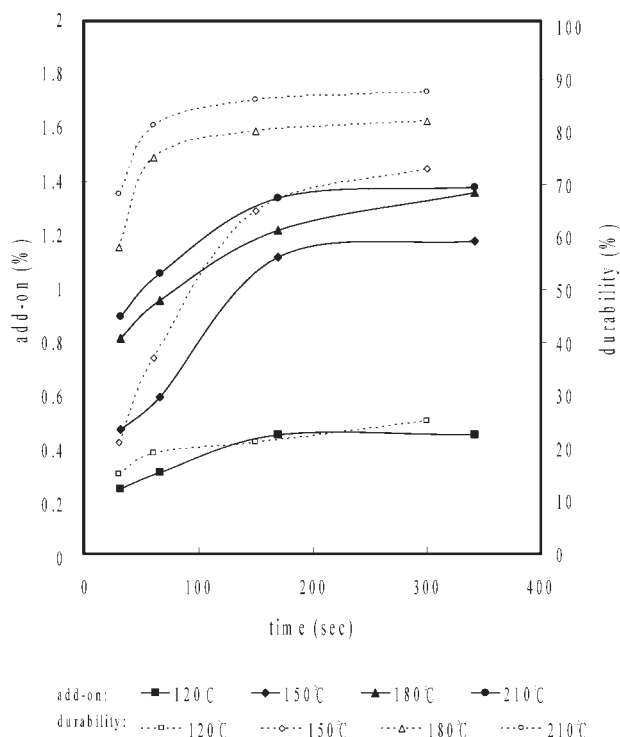
As shown in Figure 6, in 2% HSE1000 processing reagent under different processing temperatures and time lengths, the vertical wicking height of PET textiles is proportional to the add-on on PET textiles, indicating a higher hydrophilicity. Besides, a longer period of processing time when the add-on increases has more significant influence to the hydrophilicity of processed textiles. In contrast, increase of processing temperature due to a limited increase of add-on is less influential to the hydrophilic property.

**Durable hydrophilic finishing of PET fabric treated by urethane oligomers of isocyanate type**

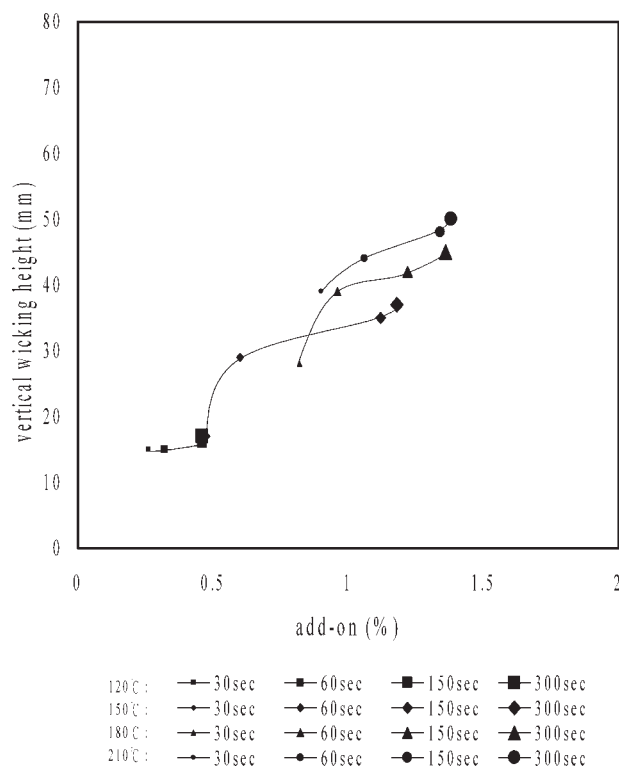
Figure 7 shows the add-on and durability of PET fabrics processed in 2% MSE1000 at different processing temperatures and time lengths. Except textiles processed at 120°C, the add-on and durability of processed textiles increased following the rise of temperature, particularly when temperature was 150°C. MSE type of urethane oligomers were prepared by NCO reactive groups blocked by MEKO, and at temperature 120°C, MEKO was not yet deblocked, so the oligomers were unable to react effectively to fix on fibers. When temperature reached 150°C, the MEKO blocking of oligomers was released, forming isocyanate groups (NCO) that after trimerization of isocyanate, isocyanurate was

produced. Alternatively, isocyanate group could react with imide groups of oligomers<sup>27,39,40</sup> so add-on and durability of processed textiles were greatly improved. When processing temperature was higher than 180°C, NCO group could produce dimerization to uretidine-diones. The motion in PET amorphous region was better, allowing chemical internalization that is beneficial to add-on.<sup>39,40</sup> The figure also clearly indicates that except the one at 120°C, the add-on and durability of processed textiles both tend to increase while the processing time extends. The one processed at 150°C has the sharpest rise, but after 150 s, it becomes gradual. This is due to that at 150°C, NCO blocking can be released to have a high reactivity. Within a very short time, the reaction can be completed.<sup>39,40</sup> Thus, the add-on and durability were increased dramatically in a short period of time.

Figure 8 shows the relationship between the add-on of PET textiles and vertical wicking height using 2% MSE1000 as a processing reagent under different processing temperatures and time lengths. The hydrophilic property of processed textiles is associated with add-on. That is when time goes on, the add-on increases leading to an increase of hydrophilic property. From the figure, it can also be found out that the effect of temperature is different from that applied to HSE type. With the same add-on, the processed textiles have a higher wicking height at a high temperature processing. At 120°C, the add-on is too low to improve the hydrophilic property of textiles.

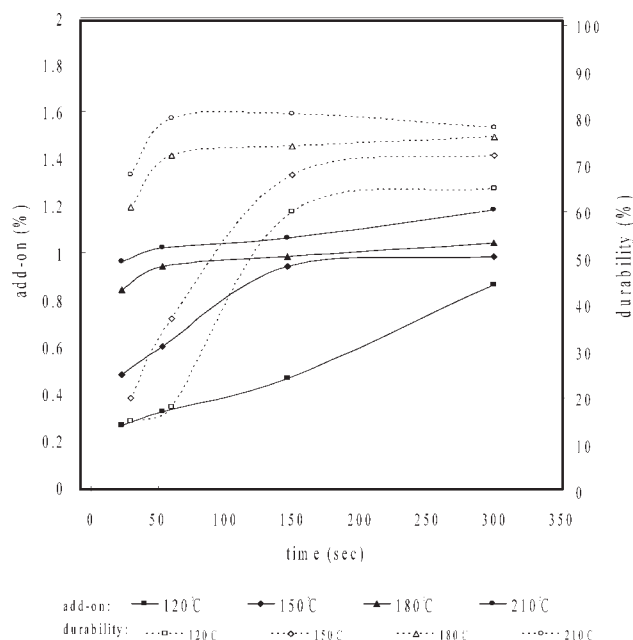


**Figure 7** The durability of fabrics treated by MSE1000 oligomer under various curing time and temperature.



**Figure 8** The vertical wicking height and add-on of fabrics treated by MSE1000 oligomer under various curing time and temperature.

However, isocyanurates are produced at 150°C, and the intermolecular alignment is irregular that can lower the formation of PEG crystallinity. Hence, the hydrophilic property is significantly improved. At



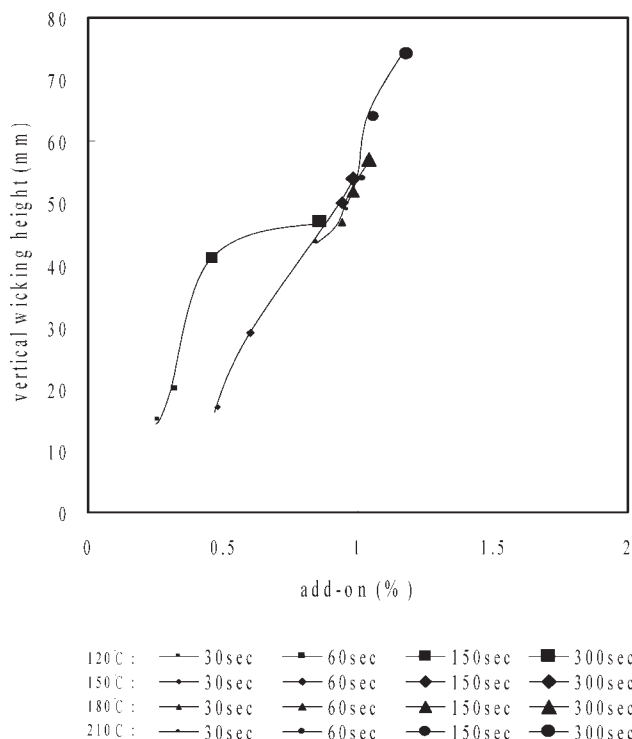
**Figure 9** The add-on and durability of fabrics treated by OSE1000 oligomer under various curing time and temperature.

temperatures above 180°C, uretidinediones are also produced, and now the PEG alignment is even more disorder causing a further improvement of hydrophilic property of processed textiles.

### Durable hydrophilic finishing of PET fabric treated by urethane oligomers of epoxy type

Figure 9 shows the add-on and durability of textiles, which were processed in the 2% OSE1000 processing reagent at different temperatures and time lengths. At low temperatures, the add-on and durability of processed textiles both increased gradually while the processing time was longer. At a high temperature for a short time, the processed textiles could obtain better add-on and durability. At lower temperatures, 120 and 150°C, as epoxide groups can only react with imide groups of urethane,<sup>41</sup> and part of epoxide groups can also open up the ring to polymerize together at hydrous condition.<sup>42</sup> Thus, a longer time is required to obtain higher add-on and durability. At temperatures above 180°C, after the ring-opening reaction of epoxide groups, the resulted carboxyl groups can dealcoholized with urethane groups forming the ring structure again.<sup>40</sup> Therefore, within a short time, better add-on and durability of processed textiles can be obtained.

Figure 10 shows the relationship between the add-on of PET textiles and vertical wicking height when



**Figure 10** The vertical wicking height and add-on of fabrics treated by OSE1000 oligomer under various curing time and temperature.



processed in the 2% OSE1000 processing reagent under different temperatures and time lengths. The hydrophilicity of textiles processed in OSE type of urethane oligomers are considerably affected by add-on more than other two types. In other words, introducing a small concentration of OSE processing reagent can obtain an excellent hydrophilic property of processed fabrics. Carboxyl groups formed by the ring-opening reaction of epoxide can dramatically increase the hydrophilic property after reaction; in addition, the carboxyl groups can influence PEG alignment, causing the difficulty to form crystalline that probably is one of the reasons.

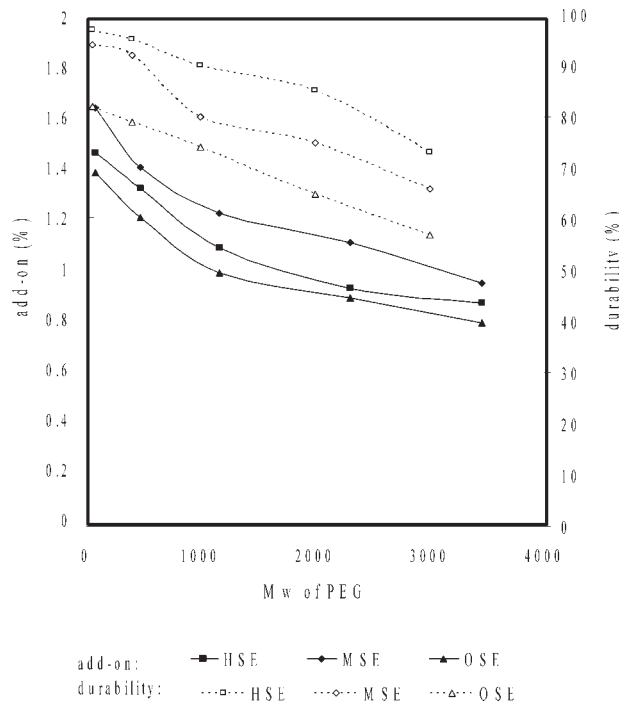
**Comparison of PET fabrics treated by various kinds of urethane oligomers**

Table II shows the physical properties of PET textiles processed in three types of oligomers having different PEG molecular weights. Figure 11 shows the add-on and durability of PET textiles processed in oligomers of three different PEG molecular weights. From the figure, it can be known that following the increase of PEG molecular weight, three kinds of oligomers conferred similar decrease trend of durability and add-on. The reasons have been illustrated before. Besides, the textiles processed in MSE have the highest add-on; textiles processed in HSE have the second high add-on; and that processed in OSE has the lowest add-on. To explain these observations, MSE is the most hydrophobic and it has the strongest NCO reactivity. Furthermore, hydrophilic OSE has poorer affinity to PET fibers. Regarding durability, textiles processed in HSE have the highest durability, and textiles processed in MSE have the second high durability. Textiles of OSE have the lowest durability. Since the free radical polymerization of HSE can be grafted to PET fibers, durability of the processed textiles is the best. MSE tends to tangle with fibers, giving a moderate degree of durability to processed textiles. After cross-linkage, OSE produces hydrophilic carboxyl groups, and thus become difficult to be appetent to hydrophobic PET that thus confer the poorest durability to processed textiles. Figure 12 shows how three types of oligomers having different PEG molecular weights affect the vertical wicking height and half-life of static electricity of PET processed textiles. As shown in the figure, three kinds of oligomers all lead to the best hydrophilic property of processed textiles as PEG molecular weight is 1000. The reasons are in connection with hydrophilic EO content and crystallinity. Except MSE type, half-life of static electricity declines as PEG molecular weight increases, indicating an improvement in electrostatic dissipating property. For MSE type, the structure of formed substances is compact, so only when PEG molecular weight is 1000, the lowest half-life of static

**TABLE II**  
**The Physical Properties of PET Fabric Treated by Oligomers**

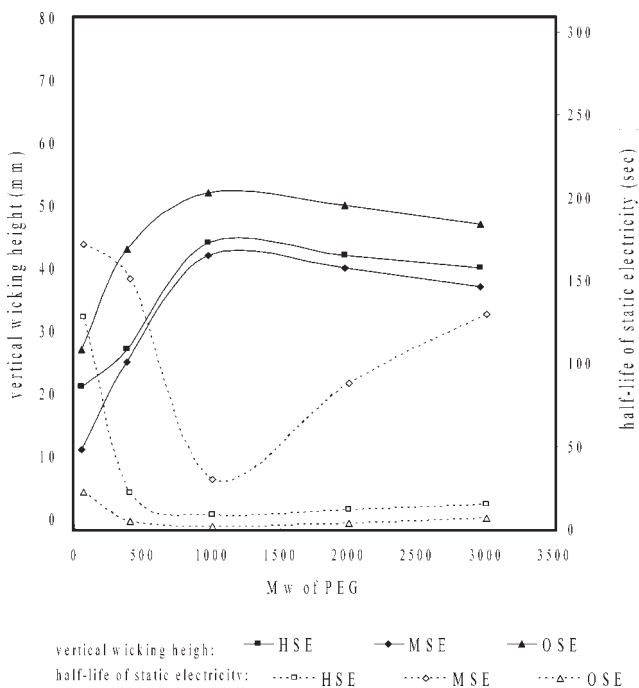
Symbol	Reactive group	Structure	Fixation rate (%)		Drop absorption time (s)		Vertical wicking height (mm)	Half-life of static electricity (s)	Breaking strength (Kgf)	Bending length (mm)
			Washing with Na <sub>2</sub> CO <sub>3</sub>	Washing 15 times with detergent	Washing with Na <sub>2</sub> CO <sub>3</sub>	Washing 15 times with detergent				
Untreated	-	-	-	-	3,600	3,600	0	720	55	26
HSE62	HEMA	62	1.46	97	292	304	21	128	30	65
HSE400		400	1.32	95	109	391	27	22	35	52
HSE1000		1000	1.08	90	20	125	44	9	37	35
HSE2000		2000	0.92	85	32	187	42	12	43	30
HSE3000		3000	0.86	73	27	238	40	15	45	33
MSE62	MEKO	62	1.64	94	429	531	11	172	35	50
MSE400		400	1.40	92	181	300	25	151	32	42
MSE1000		1000	1.22	80	52	212	42	30	40	31
MSE2000		2000	1.10	75	124	221	40	88	42	32
MSE3000		3000	0.94	66	111	201	37	130	46	35
OSE62	EPO	62	1.38	82	154	304	27	23	33	51
OSE400		400	1.20	79	89	181	43	5	35	53
OSE1000		1000	0.98	74	5	128	52	2	46	48
OSE2000		2000	0.88	65	9	157	50	4	40	35
OSE3000		3000	0.78	57	16	140	47	7	44	36

Oligomer concentration was 2%; Curing condition was under 150 s and 180°C. The vertical wicking height, half-life of static electricity, breaking strength, and bending length of fabrics were only tested in the condition after washing with Na<sub>2</sub>CO<sub>3</sub>.

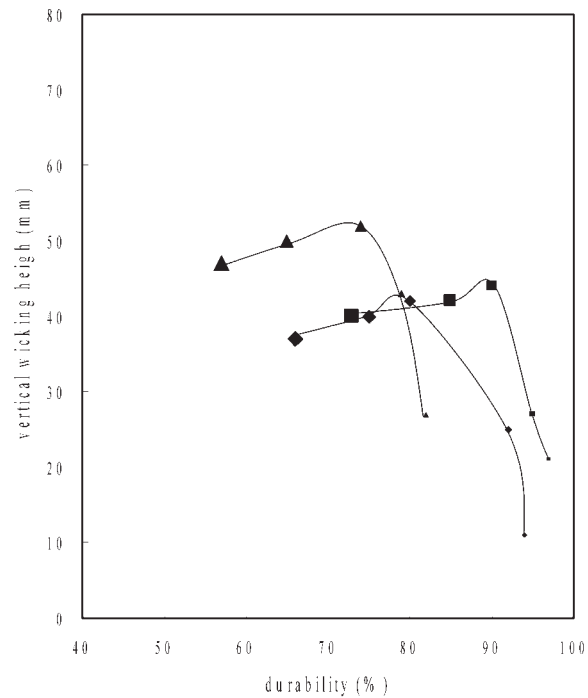


**Figure 11** The add-on and durability of fabrics treated by three kinds of oligomers with different PEG molecular weight.

electricity can be achieved. OSE and HSE formations are looser so when PEG molecular weight is more than 400, the electrostatic dissipation can be maintained at the lowest value. In terms of different kinds



**Figure 12** The vertical wicking height and half-life of static electricity of fabrics treated by three kinds of oligomers with different PEG molecular weight.



**Figure 13** The durability and vertical wicking height of fabrics treated by three kinds of oligomers with different PEG molecular weight.

of oligomer in conferring hydrophilic property and electrostatic dissipation, OSE is the best; HSE is the second; and MSE is the poorest. When hydrophilic PEG of OSE is smaller, after most reactive groups are cross-linked, a large amount of hydrophilic carboxyl groups can be produced so OSE processed textiles have the best hydrophilic property. HSE can be cross-linked to PEG chains that reduce the crystallinity of PEG so its hydrophilic property can be maintained. MSE itself is more hydrophobic and cross-linkage is more compact so it has the poorest hydrophilicity.

Figure 13 shows the relationship between hydrophilic and durability of PET textiles processed in three types of oligomers having different molecular weights. From the figure, it can be known that HSE having PEG molecular weight in 1000 can confer the best hydrophilicity and durability to fabrics.

Also shown in Table II, the tensile strength of textiles processed in three kinds of oligomers increases when PEG molecular weight of oligomers increases. Comparing to original textiles, the one processed in oligomers of lower PEG molecular weight has more loss of tensile strength because oligomers of lower PEG molecular weight have relatively more reactive groups, which tend to produce stress centralization and cause a decline of tensile strength. HSE processed

textiles have the lowest tensile strength that is lower than that processed in MSE. OSE processed textiles have the strongest tensile strength. To explain these results, HSE has grafting functions to fibers and thus damage the tensile strength of fibers. MSE structure is more compact, causing more stress centralization events. OSE structure consists of soft ether groups, which reduce the damage to tensile strength. Regarding softness of processed textiles, no matter what kind of oligomer is, the bending length decreases while PEG molecular weight increases, indicating the improvement of softness. Since textiles processed in oligomers of low PEG molecular weight have more reactive groups, so the touching feeling is stiffer. Comparing textiles processed in these three types of oligomers, HSE results in poorer softness whereas MSE and OSE lead to better softness. HSE have more cross-linking ways and can react to fibers, so HSE processed textiles are stiffer, but MSE and OSE reactions are only limited in oligomers.

### CONCLUSION

This research synthesized reactive aqueous urethane oligomers containing sulfonic groups, which were used to process PET textiles by Pad-Dry-Cure method. We then studied how different PEG molecular weights and reactive functional groups in oligomer structure affect the add-on and hydrophilic property of PET fibers under different processing temperatures, time lengths, and oligomer concentrations. The results are concluded and described below:

The add-on and durability of processed fabrics both were improved following the rise of processing temperature. When textiles were processed in HSE above 180°C, a greater durability on textiles could be achieved. When processed at low temperature 120°C, MSE could not be fixed on textiles, but add-on was improved largely at 150°C. Without considering which kind of oligomers was used, the add-on and durability of processed textiles both increased for a longer processing time. The increase of add-on slowed down after 150 s. The increase for HSE was slower. Processing time had little influence to MSE at 120°C, but at 150°C, the increase range was large. OSE at high temperatures in a short time could allow processed textiles to obtain higher add-on and durability.

Within these three kinds of oligomers, MSE led to the highest add-on on processed textiles whereas HSE processed textiles had the second high add-on, and OSE concentration fixed on processed textiles was the lowest. With respect to durability, HSE textiles were the best of durability, and MSE textiles were the second. OSE textiles had the poorest durability. OSE processed textiles possessed the best hydrophilic

property and electrostatic dissipating property which were better than that of HSE processed textiles, and MSE processed textiles were the poorest one in terms of hydrophilic and electrostatic dissipating properties. With the same add-on, OSE possessed the best hydrophilic efficiency. That is namely only a small concentration of reagent could elaborate a better hydrophilic property. Textiles processed in HSE containing PEG molecular weight 1000 could have the best hydrophilic and durability. Regardless of oligomer type, tensile strength went up along with the increase of PEG molecular weight, and in comparison to original textiles, oligomers of lower PEG molecular weights would produce larger lose of tensile strength of textiles processed. The softness of processed textiles, however, increased while PEG molecular weight increased, but to compare textiles processed in these three kinds of oligomers, HSE textiles showed poorer softness whereas MSE and OSE textiles had better softness.

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