Development of Soft Feel Coatings with Waterborne Polyurethanes

by **Lichang Zhou** and **Bernard Koltisko**
Rhodia Inc.*

Soft feel coatings applied over plastic substrates are widely used in automotive interiors and consumer products. These coatings provide a luxurious look and leather-like texture to hard plastic surfaces. Traditionally, two-component solvent-based polyurethanes have been used in these applications. In recent years, waterborne polyurethane formulations with lower volatile organic compounds have become the choice for soft feel coatings. In this article, the development of soft feel coatings with waterborne polyurethane technology will be presented. The performance of soft feel coatings based on waterborne polyisocyanates with polyester, acrylic polyols, and/or polyurethane dispersions will be discussed.

INTRODUCTION

Soft feel coatings are coatings which provide a soft touch and leather-like feeling. They are applied over plastic substrates and are widely used in automotive interiors, such as instrument panels, airbag covers, armrests, and interior door panels. Soft feel coatings are also used in consumer electronics, including cell phones, computers, vacuum cleaners, etc. The coatings used in automotive industries for soft feel applications have to meet the following requirements:

- Soft touch feeling and pleasant handle
- Resistance to chemicals—suntan lotion and insect repellent; acids, bases, water, and other cleaners
- Physical durability—adhesion, impact, scratch resistance, wear, and abrasion resistance
- Low gloss
- Weather stability
- Ambient or low temperature cure

Recently, many efforts have been made to develop waterborne polyurethane coatings for soft feel applications. These include the develop-

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*259 Prospect Plains Rd., Cranbury, NJ 08512.

ment of specifically designed waterborne polyols, functional and nonfunctional polyurethane dispersions (PUD), and hydrophilic modified polyisocyanates, as well as development of additives to enhance soft feel properties. The challenge is to improve chemical resistance, such as suntan lotion resistance, without compromising the softness of the coatings.

To make a polyurethane, one normally reacts a polymer containing hydroxyl functionality (polyol) with a polyisocyanate. Waterborne polyurethanes involve more complicated chemistry compared to traditional solventborne systems due to the presence of water. Water can compete with the reaction of the isocyanate to the polyol. The relative reactivity of aliphatic isocyanate with various active hydrogen-containing compounds is listed in *Table* 1. The slower reaction rate of aliphatic isocyanate with water compared to hydroxyl functions of polyols is the key for the success of 2K waterborne polyurethane technology. The reactions which take place in waterborne polyurethane system are shown in *Figure* 1. Water reacts with isocyanate groups generating carbon dioxide gas. At the same time, a primary amine functional species is formed, which quickly reacts with isocyanate groups to form a urea linkage. However, this side reaction cannot be totally ignored, and therefore higher NCO/OH ratios are usually used to compensate for the undesirable reaction of water with isocyanate.

In this article, we examined the impact of polyurethane chemistries on soft feel performance. This was accomplished by formulating various waterborne polyol types and PUDs with a water-dispersible aliphatic polyisocyanate from Rhodia.

EXPERIMENTAL

Four types of waterborne polyurethane coating formulations with different combinations of polymer resins have been evaluated for soft feel applications. The binders evaluated include waterborne polyester polyols, polyurethane dispersions (PUD), combination of polyester polyol with PUD, and combination of acrylic polyol with PUD. Rhodocoat® WT 2102, a hydrophilic aliphatic isocyanate, was used as the crosslinker for the various polymer resins.

A general formulation for soft feel coating in this study is given in *Table* 2, in which combinations of polyester polyols with PUDs were used as an example. For the other three types of formulations, the binders and crosslinkers were adjusted according to the suppliers' recommendations. The effect of NCO/OH ratio was also evaluated in this study.

Coated ABS panels were prepared by conventional spray techniques. The panels were flashed off at ambient conditions for 10 to 15 min after spraying. The coatings were cured at 180°F (8°C) for 30 min, and allowed to stand for one week prior to testing.

The following test methods were used in this study: Soft feel was measured subjectively by hand touch and rated on a scale from 1 to 5, with 1 being poor soft feel (hard feel) and 5 being good soft feel. Gloss was measured at 20° and 60° by ASTM D 523 test method. Persoz hardness was measured by ASTM D 4366 test method and reported in seconds. Adhesion was measured by ASTM D 3359B test method. Pencil hardness was used as an indicator for scratch resistance and was measured by ASTM D 3363 test method. MEK double

Figure 1—Reactions in waterborne polyurethane systems.

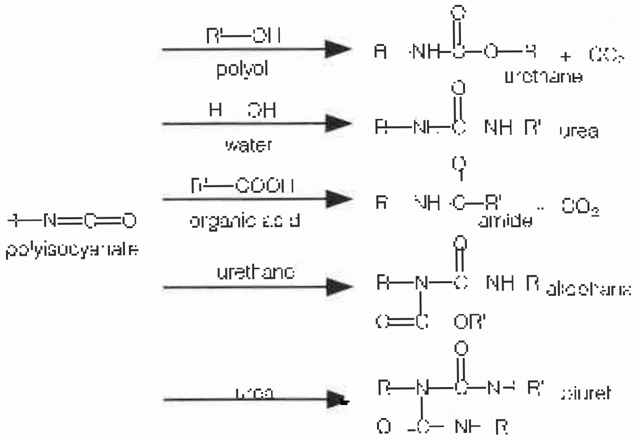


Table 1—Relative Reactivity of Aliphatic Isocyanate with Active Hydrogen-Containing Compounds[a]

Compounds	% NCO Reacted, 20°C	% NCO Reacted, 80°C
Aliphatic amine	Very high	100
Aromatic amine	10–20	100
Primary OH	2–4	30
Secondary OH	1	15
Water	0.4	6
Tertiary OH	0.01	—
Phenol	0.01	—
Urea	—	2
Carboxylic acid	—	2
Urethane	—	0.02

(a) Determined after 30 min of reaction.

Table 2—An Example Formulation (Soft Feel III) for Soft Feel Coatings

Raw Materials	Weight %	Suppliers
Component I		
Witco UCX 8256-148N	10.57	Crompton
Witcobond® W290H	23.86	Crompton
Aurasperse® W7114	20.83	Engelhard
Pergopak® M3	4.62	Lonza
Surfynol® 104DPM	0.51	Air Products
BYK® 346	0.28	Byk
Tinuvin® 292	0.29	Ciba
Tinuvin® 1130	0.29	Ciba
Deionized water	30.81	
Component II		
Rhodocoat WT 2102	7.93	Rhodia
Total	100.00	

rub resistance was measured by rubbing the surface of the cured coating with an MEK soaked wiper and reported as the number of rubs without observation of adverse effect on the coating. Reverse impact strength was measured by ASTM D 2794 test method by using cold rolled steel panels and reported in inch-pounds force (in.-lb). Chemical resistance (resistance to 10% sulfuric acid, 10% acetic acid, and 10% ammonium hydroxide) was measured by visual observation after one hour spot application of the chemical to the surface of a cured coating specimen and rated on a scale from 1 (poor) to 5 (good).

Suntan lotion resistance was measured by visual inspection after one hour spot application of ethylhexyl p-methoxycinnamate-containing suntan lotion with an SPF of 45 to the surface of a cured coating specimen and rated on the following scale:

(1) No visual effect
(2) Repairable with no visual effect
(3) Spotting discoloration observed
(4) Softening/slight dissolution of top layer observed
(5) Blistering delamination observed
(6) Coating dissolved

Figure 2—Four types of coating formulations for soft feel applications.

Elevated temperature suntan lotion resistance testing was conducted and rated in the same manner as suntan lotion resistance testing, except that the temperature of the test specimen was maintained at 74°C during the one hour spot application of suntan lotion. Insect repellent resistance was measured by visual inspection after one hour spot application of insect repellent containing 20 wt% N,N-diethyl-meta-toluamide (DEET) to the surface of a cured coating specimen and rated on the same scale as that used with suntan lotion.

RESULTS AND DISCUSSION

Although many additives can reinforce the soft feel properties of soft feel coatings, the polymer resins in the coating formulations played key roles for providing the leather feel and meeting the requirements for soft feel applications. Therefore, four types of waterborne polyurethane coating formulations with different resin combinations, as shown in *Figure* 2, were evaluated for soft feel applications in this study.

Soft Feel I: Polyester Polyol

A water dispersible polyester polyol was formulated with the hydrophilic aliphatic isocyanate and evaluated for soft feel applications. In this formula, only polyester polyol and isocyanate were used as the binder. As shown in *Figure* 3, the coating based on polyester polyol easily passed suntan lotion and insect repellent resistance testing (rating 3). However, the coating exhibited higher hardness, hence, it showed less soft touch. With NCO/OH ratio increased, the hardness increased, so did the chemical resistance, while the softness feeling was lost due to increased crosslinking density. The data in *Table* 3 indicated that the coating gave very good low gloss, good adhesion, and scratch resistance.

Soft Feel II: PUD

Several industrial available polyurethane dispersions were formulated with hydrophilic polyisocyanate Rhodocoat WT 2102 for soft feel applications (Soft Feel II). The data in *Figure* 4 and *Table* 4 listed one example from this formula. The PUD contained very low level amine functionality, which could be used for crosslinking in addition to carboxyl groups. Weight of polyisocyanate per hundred parts of component A instead of NCO/OH ratio was used in preparation of the formulation.

As seen in *Figure* 4, the coating based on PUD system provided very good soft feeling. However, good suntan lotion and DEET resistance was obtained only when a very high isocyanate concentration was used.

Figure 3—Soft feel, suntan lotion, and DEET resistance vs. hardness for Soft Feel I.

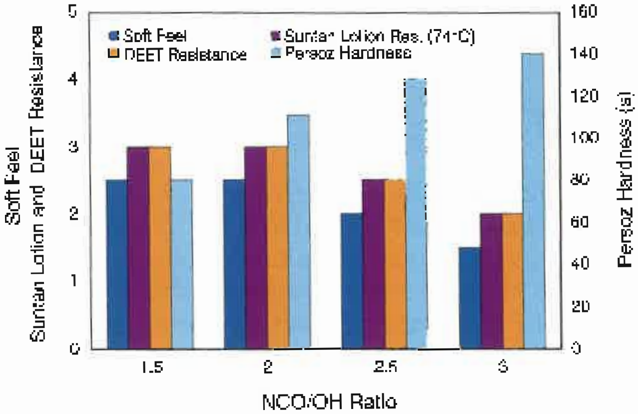


Figure 4—Soft feel, suntan lotion, and DEET resistance vs. hardness for Soft Feel II.

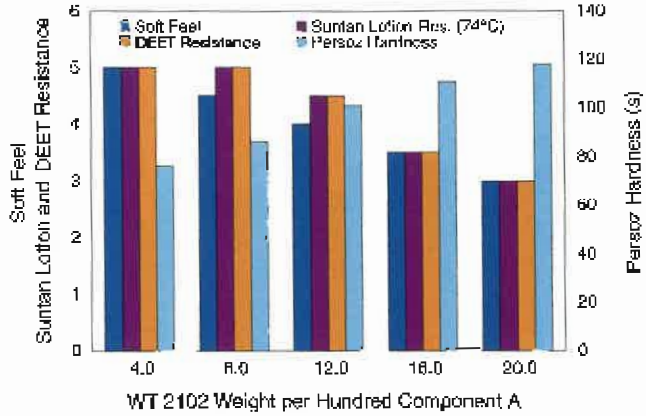


Table 3—Coating Properties of Soft Feel I

NCO/OH	1.5	2.0	2.5	3.0
Film thickness (mil)	1.6	1.7	1.6	1.7
Gloss (20°/60°)	0.2/2.5	0.2/2.6	0.2/2.7	0.2/1.8
Adhesion	100%	100%	100%	100%
Scratch resis. (pencil hardness)	2H	2H	3H	4H
MEK rubs resistance	>200	>200	>200	>200
Reverse impact (in.-lb)	>160	>160	>160	>160
1 hr spot test (5=good, 1=poor)				
10% Sulfuric acid	4–5	4–5	4–5	4–5
10% Acetic acid	4–5	4–5	4–5	4–5
10% Ammonium hydroxide	5	5	5	5

Table 4—Coating Properties of Soft Feel II

WT 2102 weight per hundred Component A	4	8	12	16	20
Film thickness (mil)	1.4	1.3	1.4	1.4	1.4
Gloss (20°/60°)	0.3/3.4	0.3/3.3	0.3/3.5	0.3/3.2	0.3/3.2
Adhesion	100%	100%	100%	100%	100%
Scratch resis. (pencil hardness)	H	H	2H	2H	2H
MEK rubs resistance	150	200	>200	>200	>200
Reverse impact (in.-lb)	>160	>160	>160	>160	>160
1 hr spot test (5=good, 1= poor)					
10% Sulfuric acid	5	5	5	5	5
10% Acetic acid	4–5	4–5	4–5	4–5	4–5
10% Ammonium hydroxide	5	5	5	5	5

Table 5—Coating Properties of Soft Feel III (polyol/PUD 50/50)

NCO/OH	1.5	2.0	2.5	3.0	4.0
Film thickness (mil)	1.3	1.4	1.4	1.5	1.4
Gloss (20°/60°)	0.2/2.7	0.2/2.6	0.2/2.4	0.2/2.5	0.1/2.2
Adhesion	100%	100%	100%	100%	100%
Scratch resis. (pencil hardness)	H	H	2H	2H	2H
MEK rubs resistance	>200	>200	>200	>200	>200
Reverse impact (in.-lb)	>160	>160	>160	>160	>160
1 hr spot test (5=good, 1=poor)					
10% Sulfuric acid	4–5	4–5	4–5	4–5	5
10% Acetic acid	4–5	5	5	5	5
10% Ammonium hydroxide	4–5	5	5	5	5

Figure 5—Soft feel, suntan lotion, and DEET resistance vs. hardness for Soft Feel III (polyol/PUD 50/50).

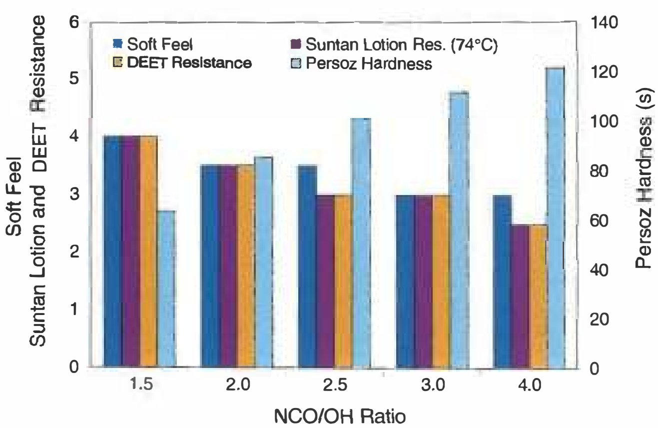


Figure 6—Soft feel, suntan lotion, and DEET resistance vs. hardness for Soft Feel III (polyol/PUD 25/75).

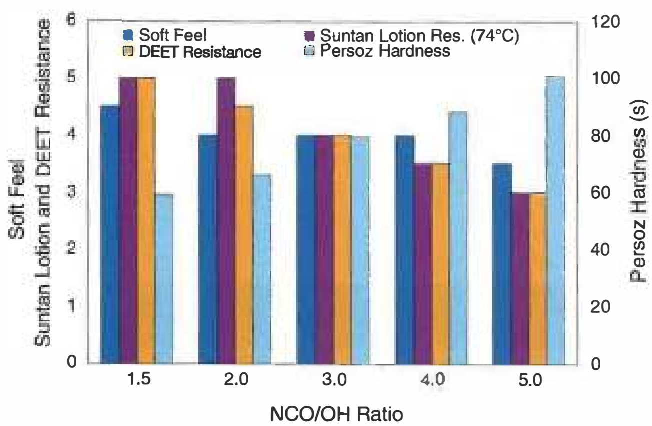
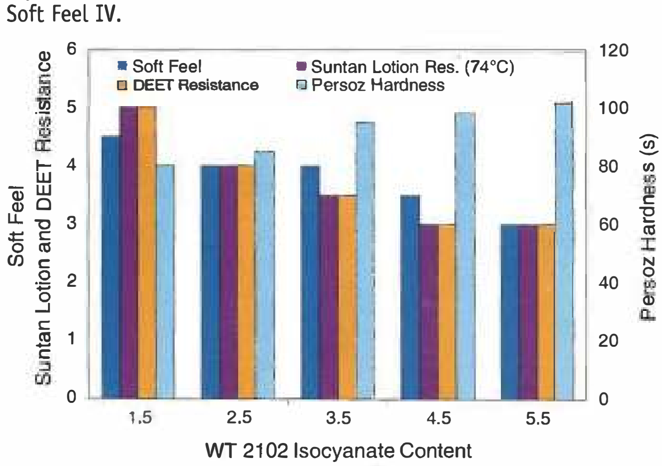


Figure 7—Soft feel, suntan lotion, and DEET resistance vs. hardness for Soft Feel IV.



With increases in isocyanate concentration, hardness, and chemical resistance significantly increased, while softness was lost. However, this coating system provided good low gloss and adhesion.

Soft Feel III: Combination of Polyester Polyol with PUD

An additional study was carried out to combine polyester polyol with PUD and formulated with hydrophilic polyisocyanate for soft feel applications (Soft Feel III). A blending ratio of polyester polyol to PUD of 50/50 and 25/75 based on solids are shown as examples. The results are given in *Figures* 5 and 6 and *Tables* 5 and 6.

It was found that coatings with good soft feel and suntan lotion resistance were obtained in this polyester polyol/PUD blended system. Soft touch properties were increased when PUD concentration in the formulation increased. As expected, the isocyanate level increased hardness and suntan lotion resistance increased, while the soft feeling characteristic decreased. The coatings showed very good low gloss and adhesion. Therefore, by adjusting the blend ratio of polyol to PUD and NCO/OH ratio, the properties between softness and chemical resistance could be balanced. In this study, good soft feel coatings were obtained when polyester polyol/PUD ratio between 50/50 to 25/75 and NCO/OH ratio between 2 to 4 were used.

Soft Feel IV: Combination of Acrylic Polyol with PUD

A combination of acrylic polyol with polyurethane dispersions was formulated with hydrophilic isocyanates and evaluated in soft feel coating applications. Very similar results were obtained as in the prior example (Soft Feel III). A higher NCO/OH ratio was needed to balance the soft feel properties with suntan lotion and DEET resistance. Data in *Table* 7 showed good low gloss, adhesion, and flexibility as well.

Why Choose a Combination of Polyol with PUD?

The challenge for soft feel coating applications is to balance the soft-touch properties and the resistance to chemicals. The former requires softness of the coating film, which is inherently low in glass transition temperature (T_g) and low in crosslinking density. The latter requires increased crosslinking density and higher T_g, which hardens the film and strengthens the coating from attack by the solvents and other aggressive reagents. The system of the combination of polyester polyol with PUD crosslinked with polyisocyanates optimized the performance, and provided the balance be-

Table 6—Coating Properties of Soft Feel III (polyol/PUD 25/75)

NCO/OH	1.5	2.0	3.0	4.0	5.0
Film thickness (mil)	1.4	1.4	1.5	1.5	1.4
Gloss (20/60°)	0.3/3.2	0.3/3.1	0.3/2.6	0.3/2.5	0.2/2.1
Adhesion	100%	100%	100%	100%	100%
Scratch resis. (pencil hardness)	F	H	H	2H	2H
MEK rubs resistance	150	200	>200	>200	>200
Reverse impact (in.-lb)	>160	>160	>160	>160	>160
1 hr spot test (5=good, 1=poor)					
10% Sulfuric acid	4–5	4–5	4–5	4–5	4–5
10% Acetic acid	4–5	4–5	4–5	5	5
10% Ammonium hydroxide	4–5	5	5	5	5

Table 7—Coating Properties of Soft Feel IV

NCO/OH	1.5	2.5	3.5	4.5	5.5
Film thickness (mil)	1.5	1.4	1.5	1.6	1.5
Gloss (20°/60°)	0.3/3.4	0.3/3.4	0.3/3.4	0.3/3.5	0.3/3.6
Adhesion	100%	100%	100%	100%	100%
Scratch resis. (pencil hardness)	F	F	H	2H	2H
MEK rubs resistance	>200	>200	>200	>200	>200
Reverse impact (in.-lb)	>160	>160	>160	>160	>160
1 hr spot test (5=good, 1=poor)					
10% Sulfuric acid	4–5	4–5	4–5	4–5	4–5
10% Acetic acid	4	4	4	4–5	4–5
10% Ammonium hydroxide	5	5	5	5	5

tween the softness of coating films and crosslinking density, or resistance to chemicals.

Soft feel coating was designed to simulate the feeling of the natural leather. The modulus of plastics, leathers, and rubbers or elastomers is schematically illustrated in *Figure* 8. At ambient conditions, plastic materials give very high modulus, while rubber or elastomers show very low modulus. Natural leather is a partially crosslinked natural polymer and shows medium modulus between plastics and elastomers. It usually shows two glass transition temperatures as well.

Soft feel coating films were analyzed via thermal mechanical analysis (TMA) and one of the examples is given in *Figure* 9. The coating film based on the combination of polyester polyol with PUD system shows two glass transition temperatures, -39°C and 57°C, which correspond to PUD and crosslinked polyol in the film. The similarity of thermal mechanical properties between soft feel coatings based on the combination of polyester polyol with PUD and the natural leather may explain the optimized performance of this type of coating for soft feel application.

Characteristics of Soft Feel

Measurement of the haptic properties (feeling of softness) of coatings by instrument is not a simple task. While great efforts have been made by many research groups, none of them showed good correlation between the data obtained by instrument and the data based on the personal sensation of test subjects. The most popular method is still to test the coating subjectively by hand feel of individuals. However, we found that a simple test, measurement of Persoz hardness, could give useful information for initial screening of soft feel coating development. We measured the soft feel coating developed in our lab and other commercially available products and found that coatings which

Figure 8—Schematic diagram of modulus of plastics, leathers, and rubbers.

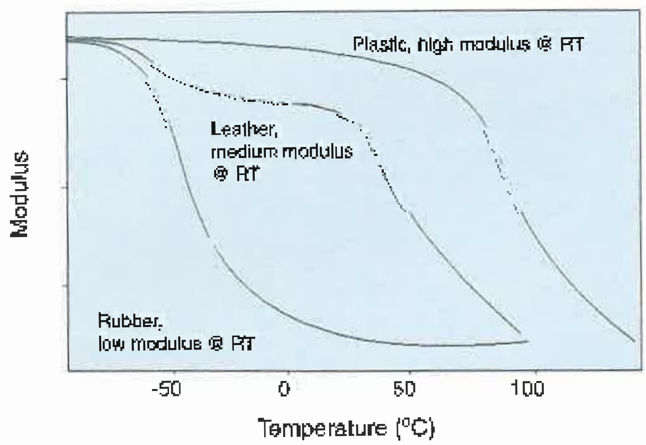


Figure 9—TMA analysis of coating film of Soft Feel III.

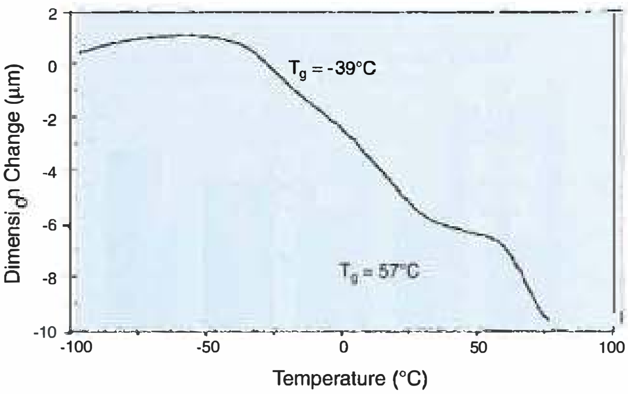
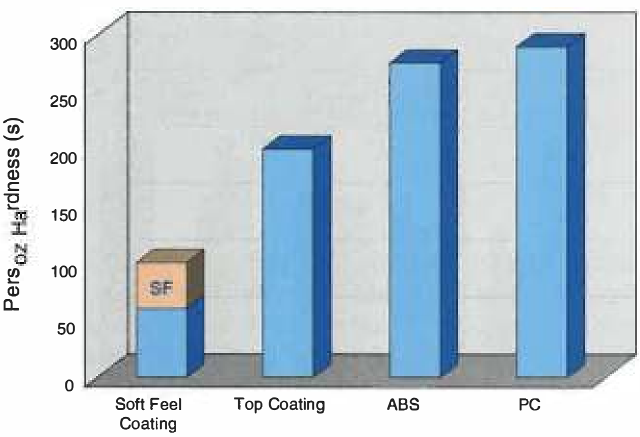


Figure 10—Persoz hardness range for soft feel coatings.



gave both soft touch feeling and resistance to chemicals had Persoz hardness of 60 to 100 sec, and preferred 70 to 90 sec. These values are much lower compared to polyurethane topcoats (150–250 sec), and plastic substrate such as ABS (~270 sec) and polycarbonates (~290 sec). We observed a good correlation between Persoz hardness and soft feel rating in our studies.

CONCLUSION

Standard polyol systems (Soft Feel I) provided coatings with very good chemical resistance, but reduced soft feel due to high hardness and crosslinking density. Polyurethane dispersion system (Soft Feel II) offered coatings with very good soft touch feel, but less resistance to chemicals. The combination of polyol with PUD (Soft Feel III and IV) balanced the chemical resistance and soft feel characteristics. As a result, optimum performance of soft feel coatings was achieved in systems combining an acrylic or polyester polyol with PUDs specifically designed for soft feel application and crosslinked with Rhodocoat WT 2102, a water dispersable polyisocyanate. CT

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