How does it feel? Recent Advances in UV-curable Soft Touch Coatings

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ABSTRACT

Soft touch coatings can enhance the perceived value of a consumer product by creating a luxurious feel on ordinary plastic, paper and metal substrates. The standard technology employed are two-part urethane systems based on multifunctional isocyanates and polyols. While these two-part systems have excellent haptic properties, they have limited pot lives, long cure times and deficiencies in coating durability. In contrast, UV-curable soft touch coatings have no pot life, cure within seconds, and the potential for increased abrasion, mar and stain resistance. Sartomer has developed new UV-curable resins which can be formulated to provide coatings with a range of feel effects and enhanced durability.

INTRODUCTION

Tactile coating can improve a consumer's perceived value of the product, so it is not surprising that interest in soft touch/feel coatings has increased in recent years. A recent study by California Polytechnic State University showed not only did customers prefer cosmetics packaged in a container with a soft touch coating versus a traditional coating, they were willing to pay a 5% price increase.[1] Other consumer products that can benefit from soft touch coatings include automotive interiors, small electronics and appliances.

The term soft feel coating is used very broadly to describe a coating that provides a soft luxurious feel to substrates such as paper, metal and plastic. While simple in concept it is actually quite difficult to achieve in practice because of the highly subjective nature of feel and the range of feel effects desired. While feel types are observer dependent, they are generally described in terms of things known to be soft: rubber, velvet, peach skin, rose petals, silk, leather, suede, etc. Achieving soft touch coatings of various feel types is necessary to fit the requirements of a wide range of applications and products.

As with other sensory observations, such as taste and smell, feel is observer dependent. A coating that one observer might describe as velvety, another may find silky. Studies have shown that factors such as age[2] and sex[3] affect how feel is perceived. In our lab studies, we chose observers of various age, sex and training. While most could recognize a soft coating, their perception of which was the most pleasing varied widely. Ideally one would remove observer variability with measurable properties, such as friction, roughness, surface energy, glass transition temperature (Tg) and modulus. However, although these properties need to be in a certain range to have soft feel, they cannot predict soft feel. For instance, a low glass transition temperature is needed to produce a soft feel, but not all low Tg coatings will feel pleasant to an observer. Instead, we found the best way to test the feel of panels is to use trained observers.

Since consumer products are exposed to repeated wear and contaminants throughout their life cycle, soft feel coatings must also be durable. Balancing the wear resistance of a coating while maintaining a soft feel is an additional challenge. Wear resistance for soft feel coatings is typically created by crosslinking multifunctional isocyanates with polyols. Although they have excellent feel properties, two-part urethane coatings have disadvantages such as pot life limitations, long cure times, and hazards of isocyanate handling. To address these issues as well as to improve durability formulators and product designers look increasingly toward UV-cured soft feel coatings.

Two-part isocyanate systems create a structure with hard regions from the isocyanates distributed in softer regions created by the polyols, as can be seen in the idealized structure in Figure 1. The structure created is very regular because polyols can only react with isocyanates and visa versus. In a UV-system one cannot easily control one type of acrylate reacting with itself or a different acrylate. Consequently a less regular structure is formed when hard and soft acrylic monomers/oligomers are combined in a UV-curable system, Figure 2. Despite the lack of a regular structure of hard and soft segments, the proper selection of oligomers and monomers can create a UV-curable soft feel coating with improved properties over a traditional two-part urethane.

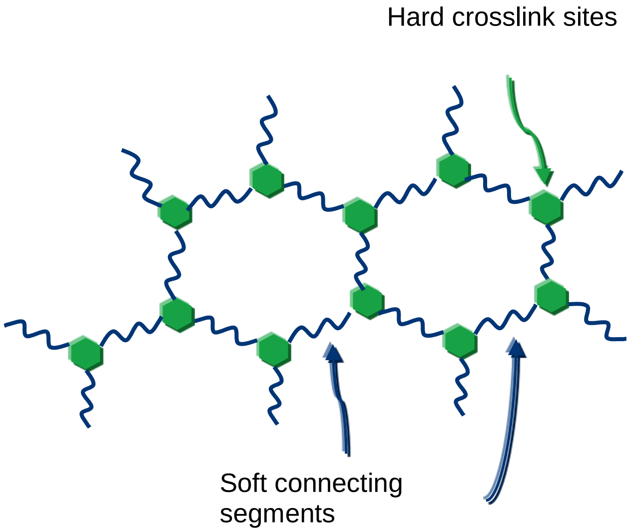


Figure 1 - Idealized 2 part soft touch coating structure

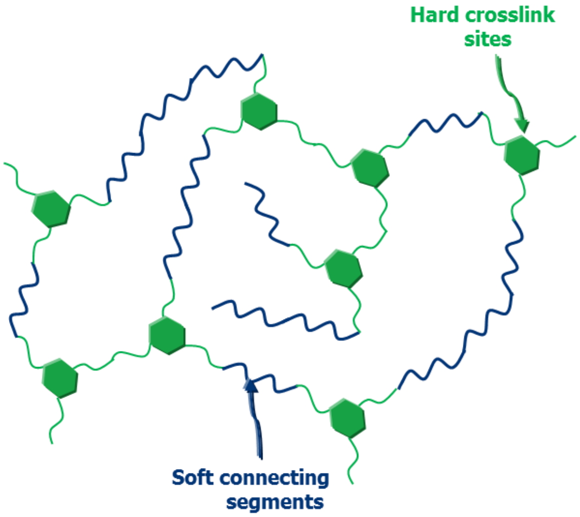


Figure 2 - Idealized UV-curable soft touch coating structure

EXPERIMENTAL

We chose difunctional urethane acrylate oligomers (UA) to mimic the softer polyol regions in the traditional two-part systems and trifunctional acrylate crosslinkers (C) for the harder isocyanate regions. We utilized a design of experiments (DOE) to investigate the effect of different backbone chemistries and molecular weights of the urethane acrylate oligomers and crosslinkers on the final film properties. We selected acrylates of varying molecular weight and chemical backbone composition to achieve a range of glass transition temperatures (Tg) and moduli of the cured films. Five difunctional urethane acrylate oligomers (UA1, UA2, UA3, UA4, and UA5) and five trifunctional acrylate crosslinkers (C1, C2, C3, C4, and C5) were chosen for the initial DOE at a high and low ratio of UA to C of 90:10 and 60:40, respectively.

Solid particle surface additives, including silica and polymeric waxes, play an important role in imparting soft touch effects.[4] Therefore, we incorporated silica (8.5 wt% on resin) in all formulations as both a surface additive and matting agent. The effect of a polyurethane polymeric wax on soft feel properties was screened at 0 and 5 wt% on resin. The silica and polyurethane wax were dispersed in the formulation after dissolving the acrylate resin, photoinitiator, and dispersant into solvent. Solvent reduces the viscosity of the formulations and provides enough shrinkage to allow for the migration of the solid particles to the film surface, reducing friction and impart a soft feel.[4]

After applying the formulations, the panels were dried for 15 minutes at 60°C to remove the solvent. The coatings were then cured with two mercury arc lamps at 400 W/in and a belt speed of 50fpm resulting in a final film thickness of 2 mils. The panels were allowed to stand overnight before testing for abrasion, solvent, food stain, sunscreen, and insect repellent resistance, hardness, and adhesion. A detailed list of test methods can be seen in Table 1.

Table 1: Summary of Test Methods for Soft Feel Coatings

Test	Method	Purpose
MEK double rubs	ASTM D5402-06	Solvent resistance
Stain resistance	ANSI/KCMA A161.1 with color change measurement	Food stain resistance
Personal care product resistance	General Motors procedure GMW14445	Sunscreen and insect repellent resistance
Pencil Hardness	ASTM D3363-05	Hardness and mar resistance
RCA abrasion	ASTM F2357-10	Finger wear resistance
Adhesion	ASTM D3359-09	Adhesion to ABS plastic

Experienced observers rated the feel for the panels by type and quality. We divided the range of observed feel into three regions: rubbery, velvety, and silky. Rubbery describes a coating close to rubber, which has more grip (less slip) than a silky (silk-like feel) coating. A velvety coating has a slip/grip feel between that of rubbery and silky. The observers also rated the quality of the soft touch on a scale of 1 to 5, with 1 being a poor match and 5 being an exact match to the coatings respective feel type.

Test results for UV-cured coatings were compared to a commercially available solvent based two-part urethane coating. Drawdowns were dried for 15 min at room temperature and cured for 45 minutes at 70°C. Test methods are described above. To determine if UV-cure can be used to improve the two-part urethane's properties without being detrimental to the feel, the best combination of urethane acrylate oligomer and crosslinker was added to the two-part urethane. The solvent was removed by drying at room temperature. The panels were cured with two mercury arc lamps at 400 W/in and a belt speed of 50fpm and baked 45 minutes at 70°C.

RESULTS AND DISCUSSION

Of the variables screened in the DOE (UA type, C type, UA:C ratio, and polymer wax) it was apparent the polymer wax had a significant detrimental effect on feel. Coatings containing the selected polyurethane wax had a rough texture that lead to an unpleasant feel. An additional study screening other polymer waxes demonstrated there are polymer waxes that do not have a detrimental effect on feel but also no significant improvement to feel over silica. A potential benefit of using polymer wax is the ability to decrease the amount of silica required, reducing formulation viscosity and improving coatability.

From the other variables screened (UA type, C type, UA:C ratio), a trend was not immediately apparent between formulation and feel. We made several attempts to correlate physical properties with feel properties of the cured coatings but were unable to identify any strong relationships that would allow us to improve and tailor the feel. Therefore, we selected several "extreme" cases to determine a qualitative relationship between resin composition with feel and coating properties, Figure 3 and Tables 2 and 3. The difficulty we encountered creating correlations is apparent when looking at the feel versus the Tg or modulus. For example, coatings from DOE formulations 3 and 26 have a Tg of less than -40°C and while both have poor durability, only one has poor haptic properties. Similarly, DOE formulations 4 and 9 form durable high moduli coatings with varying feel qualities. Due to the complicated nature of feel, it is likely that no single variable can predict the perceived softness. However, we are continuing to study correlations between chemical structure, measurable coating properties, and feel.

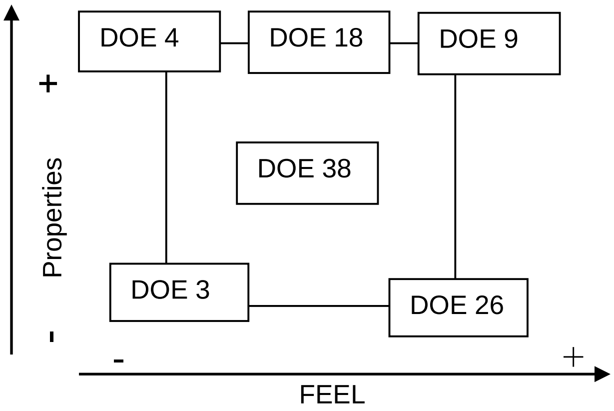


Figure 3 – Selected “extremes” from DOE for further analysis

Table 2 – Feel vs Durability for Selected DOE “Extremes”

Formulation #	**Urethane Acrylate Oligomer**	**Urethane Acrylate Loading**	**Crosslinker**	**Type of Feel**	**Quality of Feel**	**Durability**
3	UA3	0.9	C1	Rubbery	poor	poor
4	UA1	0.6	C1	Velvety	poor	good
9	UA4	0.6	C4	Silky	good	good
18	UA2	0.6	C1	Silky	medium	good
26	UA3	0.6	C5	Rubbery	good	poor
38	UA5	0.9	C2	Velvety	good	medium

Table 3: Properties for Select Formulations

DOE #	**Urethane Acrylate Oligomer**	**Urethane Acrylate Loading**	**Crosslinker**	**Quality of Feel**	**Durability**	**Storage Modulus at 25C (MPa)**	**Tg storage modulus**	
							1	**2**
3	UA3	0.9	C1	poor	poor	3.14	-42.83	NA
4	UA1	0.6	C1	poor	good	730.8	-10.89	78.27
9	UA4	0.6	C4	good	good	335.2	-20.51	82.16
18	UA2	0.6	C1	medium	good	701	17.83	69.33
26	UA3	0.6	C5	good	poor	3.01	-48.66	NA
38	UA5	0.9	C2	good	medium	4.4	-23.64	NA

Table 3 shows a generalized rating for coating durability of the selected DOE formulations. Figures 4 and 5 rate specific properties (solvent, stain, and abrasion resistance, and hardness), along with feel of formulations with lower and higher coating durability, respectively. Both plots include the two-part urethane coating as a reference. DOE formulations 9 and 38 demonstrate that it is possible to improve durability with only a slight impact on the overall feel.

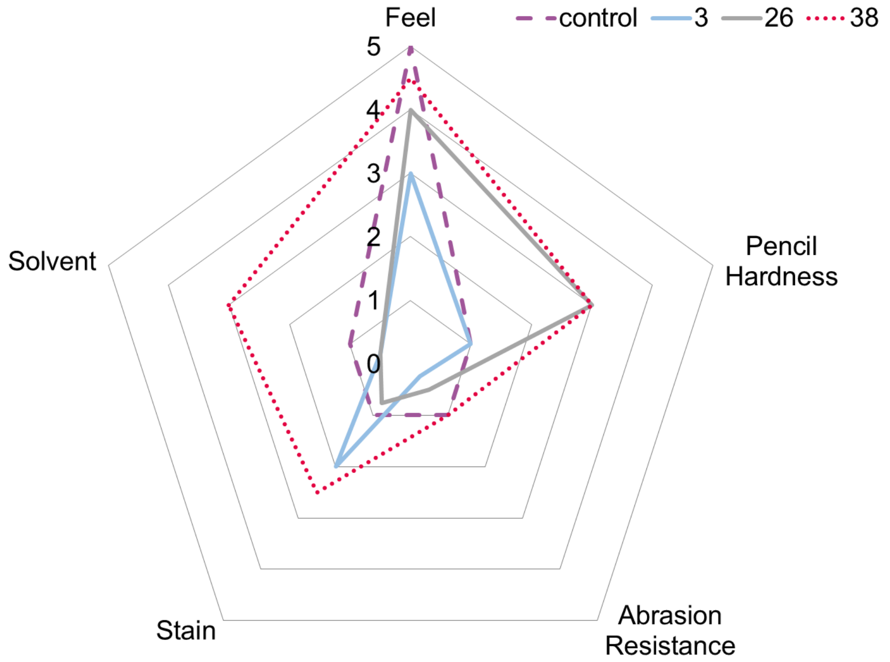


Figure 4 – DOE formulations with lower coating durability.

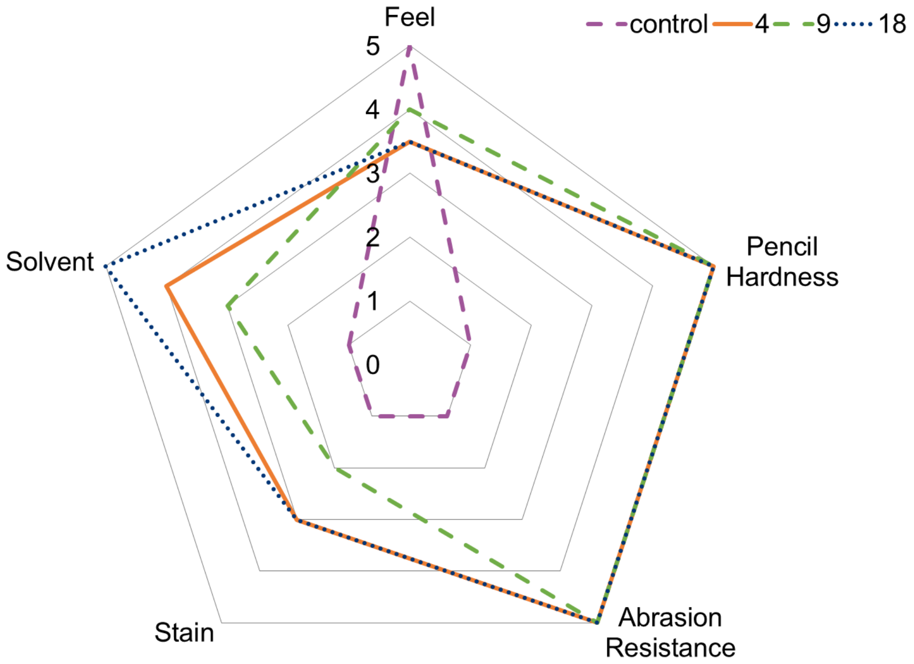


Figure 5 - DOE formulations with higher coating durability.

Since DOE formulations 9 and 38 had the best feels with improved properties versus the two-part urethane, we examined the urethane acrylate oligomers used in these formulations, UA4 and UA5, further. An expanded study was created using crosslinker C1 at urethane acrylate oligomer to crosslinker weight ratios of 60:40 and 90:10, Table 4. The amount of crosslinker was varied to determine its effect on feel type. Overall the formulations with UA5 had better feel and properties than the corresponding formulations with UA4. Both a silky and velvety feel were created with UA5 by reducing C1 content from 40% to 10%, formulation 41 to 42. Unfortunately, the reduction of crosslinker decreased the durability of the coating significantly. Thus, a reduction of crosslinker alone cannot be used to change the feel type.

Table 4 – Expanded DOE with Selected Urethane Acrylate Oligomers

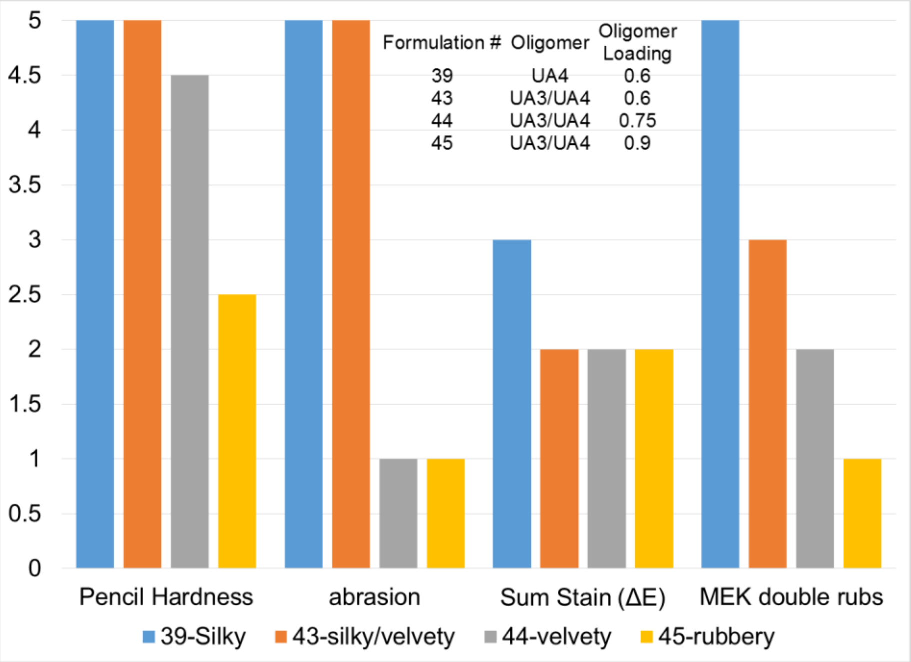
DOE #	Urethane Acrylate Oligomer	Urethane Acrylate Loading	Type of Feel	Feel rating	Pencil Hardness	MEK double rubs	RCA Abrasion	Sum Stain (ΔE)
39	UA4	0.6	Silky	4	F	190	300+	39
40	UA4	0.9	Silky	3	B	17	31	58
41	UA5	0.6	Silky	4	H	200+	300+	42
42	UA5	0.9	Velvety	4.5	B	26	98	47

To create range of feel types with improved durability, we investigated the effect of combining the urethane acrylate oligomers while also varying the crosslinker concentration. UA3 was selected for blending because it created formulations with a rubbery feel type in the original DOE, Table 2. Unfortunately formulations with UA3 had poor durability, so we combined it with UA4 or UA5 to improve the film properties. Table 5 shows the combinations of urethane acrylate oligomer and crosslinker concentration studied.

Table 5 – Formulations with Blended Difunctional Urethane Acrylate Oligomers

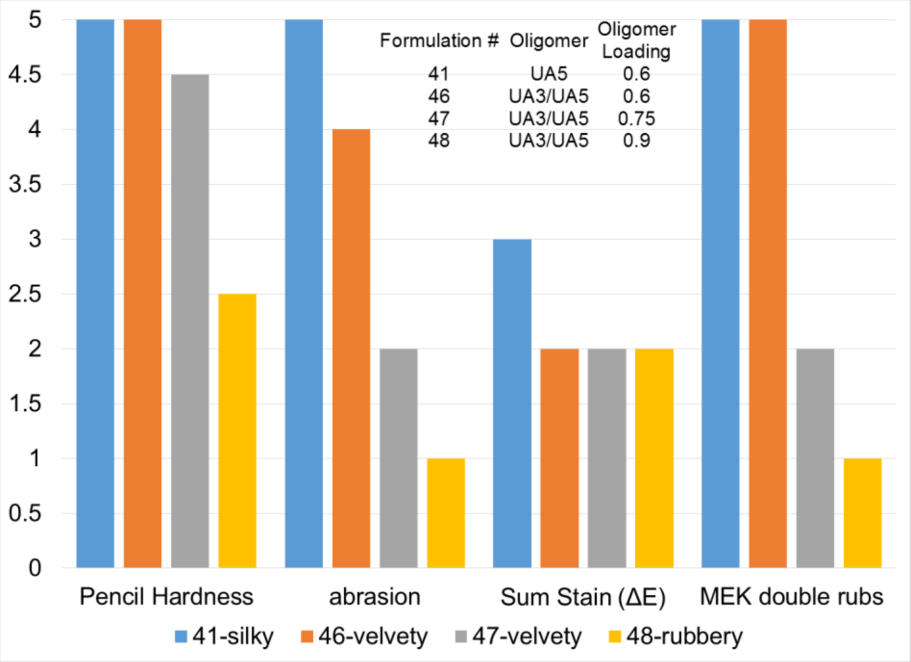
Formulation #	Urethane Acrylate Oligomer	Urethane Acrylate Loading	Crosslinker
43	UA3/UA4	0.6	C1
44	UA3/UA4	0.75	C1
45	UA3/UA4	0.9	C1
46	UA3/UA5	0.6	C1
47	UA3/UA5	0.75	C1
48	UA3/UA5	0.9	C1

Figures 6 and 7 show the results of blending UA3 with UA4 or UA5, respectively. Blends of UA3 with either UA4 or UA5 create a rubbery coating, with 10% crosslinker on resin. Blending UA3 with UA5 holds several advantages over UA3 with UA4. First, we achieve a feel with more grip (rubbery or velvety) using UA5 without the need to decrease the crosslinker as much. The ability to use higher levels of trifunctional crosslinker is advantageous as it allows for higher crosslink density and better coating durability. In addition, the blends with UA5 had a better overall feel quality than blends with UA4 (not shown in figures). Thus, we selected the blend of UA5 with UA3 for further studies.



Formulation #	Oligomer	Oligomer Loading
39	UA4	0.6
43	UA3/UA4	0.6
44	UA3/UA4	0.75
45	UA3/UA4	0.9

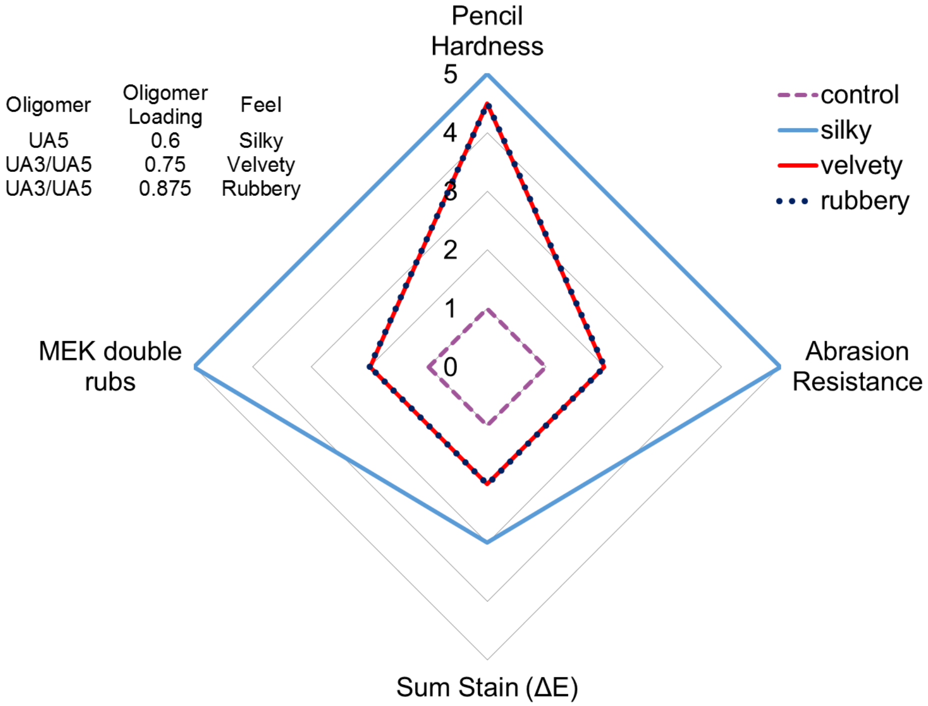
Figure 6 – Properties of blends of UA4 with UA3 as a function of crosslinker content



Formulation #	Oligomer	Oligomer Loading
41	UA5	0.6
46	UA3/UA5	0.6
47	UA3/UA5	0.75
48	UA3/UA5	0.9

Figure 7 – Properties of blends of UA5 with UA3 as a function of crosslinker content

While we were able to achieve a rubbery feel at 90% urethane oligomer (UA3/UA5) and 10% crosslinker (C1), the films did not have the desired durability. Therefore, we investigated increasing the level of crosslinker. Figure 8 shows at 17.5% crosslinker C1, a level between 10% and 25% (velvety coating), we were able to achieve a rubbery coating with improved properties over the two-part urethane control. Figure 8, also demonstrates our ability to achieve UV-cured coatings of all three types of feel with improved properties over a two-part urethane based system.



Oligomer	Oligomer Loading	Feel
UA5	0.6	Silky
UA3/UA5	0.75	Velvety
UA3/UA5	0.875	Rubbery

Figure 8 – Tailorable feel by adjusting oligomer type and crosslinker concentration

A large difference in coating properties between the two-part urethane control and the UV-cured silky formulation is apparent, Figure 8. We investigated improving the properties of the two-part part urethane control by adding the acrylate resin from the silky formulation (60:40 UA5:C1) to the control. The modified coating was cured both thermally and with UV-light to complete the urethane reaction and the free radical reaction, respectively. Table 6 shows that the coating properties of the two-part 2 part urethane can be increased without changing the soft feel. These results show the utility of UV technology to improve the durability of conventional soft feel coatings.

Table 6 – Properties of Dual-cured Soft Feel Coating

Formulation	Acrylate Loading	Type of Feel	Pencil Hardness	MEK double rubs	Sum Stain (ΔE)	Bug Spray Resistance
1	0	Velvety	7B	24	51	Fail
2	0.2	Velvety	3B	47	38	Pass

CONCLUSIONS

The proper selection of urethane acrylate oligomers and crosslinker create UV-curable soft feel coatings with improved durability over the industry standard two-part urethane coatings tested. In addition to enhanced durability, the UV-curable systems have infinite pot life, short cure times and no free isocyanate. A range of haptic sensations can be created by adjusting the crosslinker concentration in an appropriate urethane oligomer blend. The blend of urethane acrylate oligomer and crosslinker can also be used to improve the durability of a two-part soft feel coating. We continue to investigate the relationship between the coating's measurable physical properties and feel, as we work toward a solvent free UV-curable soft feel coating system.

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