High Performance Keyboard Coatings

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Introduction

The ever growing and constantly changing electronic industry has established very stringent requirements for the durability and aesthetic appearance of computers and mobile input devices. Computer keyboards, the most commonly used input devices, tend to wear under everyday use. Acrylonitrile butadiene styrene (ABS) keyboard keys become glossy and often legends are erased with constant use. This wear can be prevented by the use of high performance UV curable anti-glare protective coatings applied by the spray process.

Background

The UV curable protective coatings for computer keyboards have to meet a demanding set of conflicting specifications. Some of them are low gloss, extended abrasion and wear resistance, transparency, temperature and humidity tolerance, high pencil hardness and acceptable aesthetic appearance. In addition, these coatings have to be cost effective and meet stringent international health, safety and environmental requirements.

Majority of the keyboards manufacturers demand coatings with low gloss levels. It has been proposed that gloss levels at 3 to 5 gloss units are best suited for computer keyboards, where the unpleasant glare is reduced significantly to provide minimum distraction to computer users. In addition to reducing light reflection, low gloss coatings usually hide fingerprints and provide better visual appearance. Typically, low gloss coatings are obtained by incorporating matting particles with various sizes into the UV curable formulation. Low gloss coatings require substantial amount of matting agent. Usually, the higher the amount of the particles the lower the abrasion resistance is. The industry has adopted numerous tests for abrasion and wear resistance the most challenging of which are key wear durability and legend abrasion tests. Both tests are performed on an abrasion tester as shown on **Figure 1**. Wear durability involves linear abrasion with CS-5 Taber Industries® Jumbo Wearaser under 200 g load. The keycap coating should withstand 250000 cycles at 38mm stroke, 36 cycles per minute without visible change to the surface. The legend abrasion test is performed with Taber Industries® Wearaser CS-10F under 500 g weight load at 9.5 mm stroke at 26 cycles per minute. After 1250 cycles the legend should not show any visible wear.

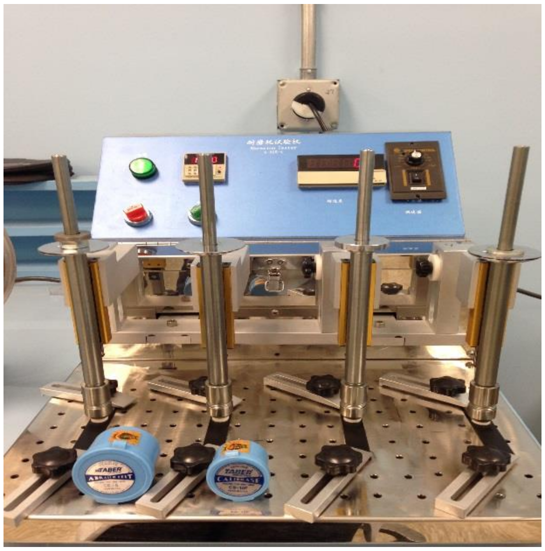


Figure 1. Abrasion tester

Other key technical aspects for keyboard coatings that have to be taken into consideration are high chemical resistance to household cleaners and chemicals as well as resistance to varied temperature and humidity conditions computers might be exposed to. Matting particles and coating additives which are not chemically bound to the resins tend to migrate to the surface when the coating is exposed to harsh environmental conditions, leading to whitening of the surface and/or lowering of the wear resistance of the coating. The UV curable anti-glare keyboard coatings transparency is essential as they are applied over screen printed legends.

Gloss Reduction Considerations

Most often, the anti-glare effect in coatings is achieved by use of matting agents[1-5]. The degree of resulting matte finish is a function of the degree of the surface roughening and is represented as gloss. Gloss is an optical property of a surface to reflect light in a specular direction. Micro rough surfaces diffusely scatter the incident light and reduce the amount of reflected light. The light-diffraction phenomenon is rather complex process that depends on the particle size, chemical, physical and morphological properties of the matting agents.

One of the most powerful gloss reducing particles are silica particles[1-5]. Most of them are fairly easy to incorporate and are cost effective. We have probed several grades silica particles into a model UV- acrylate system (*ca.* 30% resins) achieving coating with desired gloss level. **Figure 2** demonstrates the efficiency of gloss reduction for different grades of silica. The percentage represents the overall amount of silica in the UV curable coating formulation. The gloss is measured with BYK® micro-gloss meter at 60 degrees. While the desired gloss can be easily achieved the coatings are not the best performers in the long-term wear resistance test or lack the required smooth appearance. Greater particle size silica requires smaller amount of matting agent but produce quite rough, dry and unpleasant to touch surfaces at low coating thickness. The smaller particles, on the other hand, produce smoother coating finish but require higher load. High loads of silica lower the abrasion and wear resistance of the resulting coating. Generally, silica particles are easily dislodged and embedded into the wool pad during the wear test described above. The entrapped particles act as additional abrasive media leading to fast destruction of the coating finish. Wax treated silica particles produce smoother and more slippery coating finish which tends to polish upon wear test. Combination of different size and types of silica contributes to better packing of the particles at the surface and produce smooth finish. We have found that silica S5 (**Figure 2**) produces considerably smooth coating finish at 12-14 µm coating thickness withstanding the long term abrasion test without polishing or scratching.

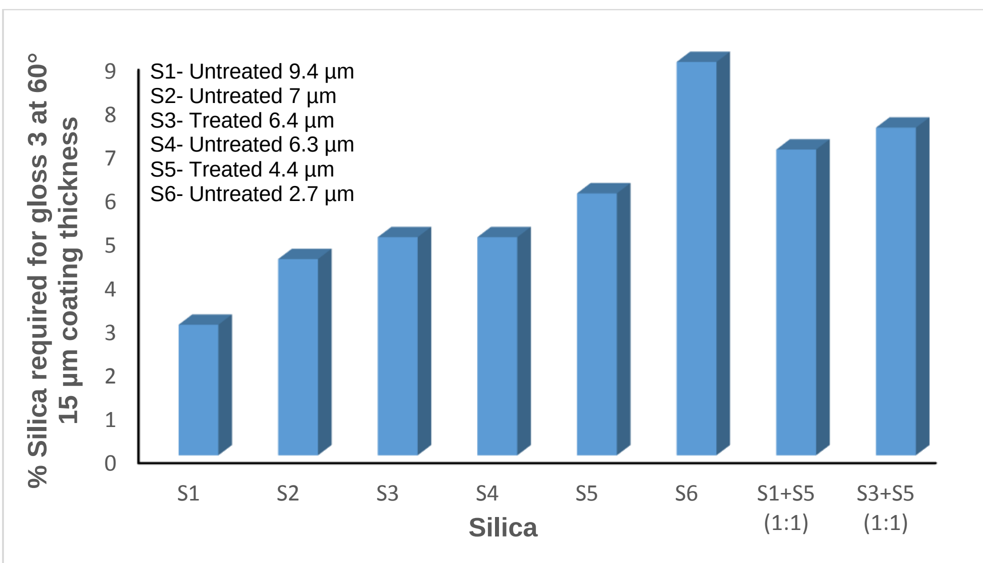


Figure 2. Gloss reduction power of different grades silica in UV-acrylate system

The gloss reduction efficiency is a function of not only particle size but also of coating thickness. **Figure 3** shows the gloss dependency of a model UV-acrylate system as a function of coating thickness and load of matting agent with an average particle size of 3 µm. Higher percentage of matting agent at low coating thickness produces low gloss coatings but the surface smoothness is compromised. As the thickness increases the surface becomes smoother but the gloss gets higher.

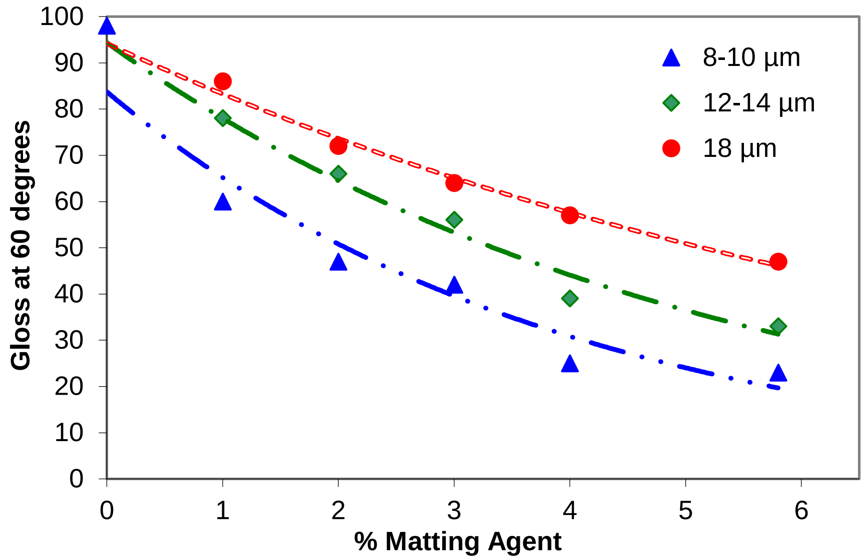


Figure 3. Gloss dependence as a function of coating thickness and matting agent load

Numerous mineral fillers such as kaolin, cristobalite, calcium carbonate, etc. have been screened as potential matting additives in the UV curable coatings for keyboards. The tested compounds either influence the opacity of the coating or diminish the abrasion resistance. However, we have noticed an interesting effect with ceramic microspheres. Although not efficient gloss reducers, ceramic microspheres contributed to increased pencil hardness. Average pencil hardness of the model UV acrylate system applied on polycarbonate at dry film thickness of 8-10 µm is 1 H. The same coating with 6% load of ceramic spheres increases the pencil hardness to 2H. The gloss, however, is reduced to 23 units at 60 degrees. Additional amount of ceramic microspheres doesn't result in substantial gloss reduction. Further matting effect is achieved by the addition of silica. This way, the gloss requirements can be met but the abrasion resistance and pencil hardness are deteriorated. As expected, when greater particle sizes of ceramic spheres are used the coating surface becomes coarser.

Finely grained organic matting materials gained a lot of popularity in recent years. Contemporary grinding techniques allow for producing particles with round shape and very narrow particles size distribution. The latter promote soft feel effect. Typically, organic particles are easy to disperse and have very low effect on the formulation viscosity[6]. Other advantage of these particles is their chemical resistance and temperature stability. Micronized PMMA beads, polymethyl urea resins, polystyrene and polyamide resins have been screened as matting agents. The effect of particle size, coating thickness and amount of load on gloss reduction follows the same pattern as observed for silica. The major difference is the gloss reduction efficacy and behavior upon wear test. **Figure 4** demonstrates the gloss efficiency of several organic matting agents with average particles size of 5 µm at 5% load at 15 µm coating thickness of the model UV coating. The coating surfaces are considerably smoother in comparison to these of silica containing coatings but exhibit polishing upon wear test.

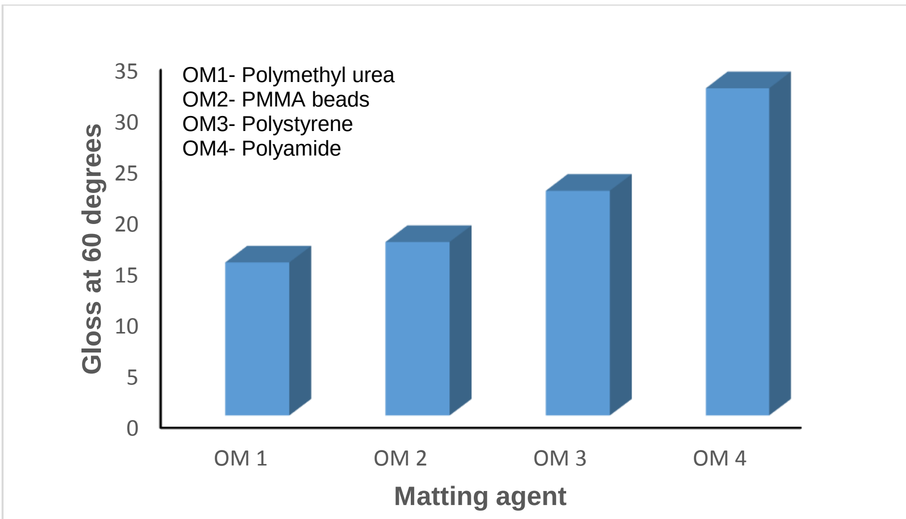


Figure 4. Gloss reduction with organic matting particles

Micronized waxes, such as polyethylene, polypropylene, amide and Carnauba are common additives to coatings known to significantly improve surface properties. Waxes tend to migrate to the coated surface thus improving slip, mar, rub, scratch and abrasion resistance[7]. Some types of waxes are suggested for matting and gloss control. Their gloss reduction efficacy is considerably lower than that of silica and organic matting agents. In combination with other matting agents, the waxes contribute drastically to improve surface properties of anti-glare coatings. We have tested several waxes in combination with silica, achieving high performance UV curable protective coatings for keyboards. The best combination of properties and visual appearance is achieved at dry coating thickness of approximately 8 µm.

The type of the acrylic resins incorporated into the anti-glare formulation contributes to the overall coating gloss. **Table 1** illustrates the overall gloss achieved with solvent borne anti-glare formulations using different resins and the same amount and type of matting agents. While common multifunctional acrylate monomers and oligomers produce coatings with similar gloss, silica nanocomposite in acrylate leads to lower gloss with the same amount of matting particles. Abrasion resistant studies show that silica nano composites in acrylate enhance the long term abrasion resistance and do not influence pencil hardness.

Table 1. Gloss reduction and abrasion resistance of coatings using different resins

Type of resin in solvent borne anti-glare formulation	60° Gloss at 8 µm coating thickness on polycarbonate	Taber[a] 100 cycles	Taber[a] 500 cycles	Pencil Hardness[b]
Multifunctional acrylate	15	2.3	9.4	H
Polyether acrylate	13	3.2	7.0	H
Polyurethane acrylate	15	2.8	8.5	H
Silica nanocomposite in acrylate/ multifunctional acrylate (1:1)	5	1.8	2.3	H

[a]ASTM D-1044, CS-10 wheels, 500g load @ 100 and 500 cycles %Δ – Haze – PC data
[b]ASTM D-3363, 750 grams @ Mitsu-Bishi Hi Uni pencils – PC data

Keyboards are produced by different manufacturers and keycaps differ in type of material, thickness, color, gloss and surface texture. Some materials require substantial coating thickness in order to cover the surface and hide the keycap imperfection and surface roughness. Thus, coatings with dry film thickness above 15 µm become necessary. Such coatings require more load of matting particles; create issues with UV cure at low irradiance and typically compromise wear resistance and transparency. To overcome problems associated with thick coatings we have turned our attention to UV curable self-matting resins. Such agents produce smooth particle free finish. Several acrylate resins, polyurethane acrylates and polyester acrylates possessing self-matting properties have been screened. **Figure 5** shows values of minimum gloss achieved utilizing UV curable self-matting resins at 15 µm thickness. The self-matting resins are less sensitive to solvents and flash off temperatures.

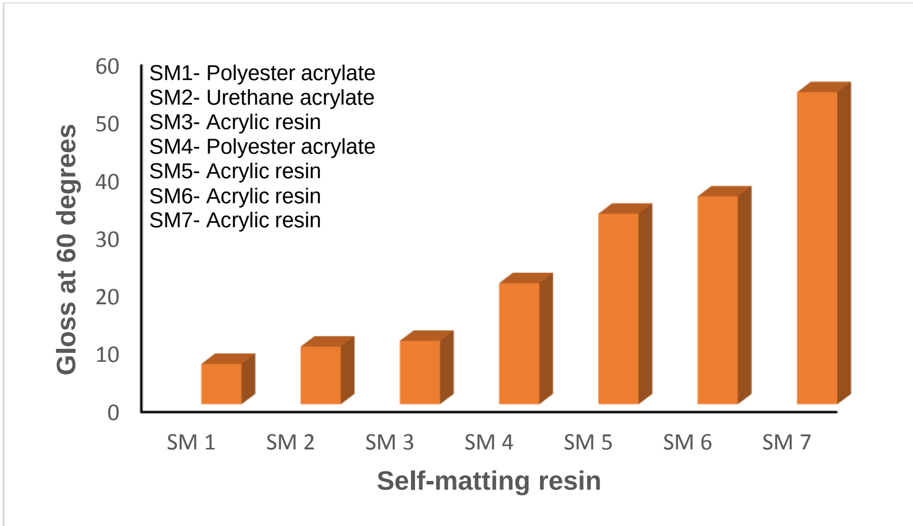


Figure 5 Gloss reduction with self-matting resins

High Performance Keyboard Coatings

Numerous anti-glare coating formulations have been applied and tested. Based on their overall performance we have selected three UV curable coatings. Major properties of these low gloss UV curable coatings are outlined in **Table2**. **Coating 1** is a premier coating which possesses exceptional wear and chemical resistance at a low dry film thickness. The chemistry is based on combination of nano technology and conventional acrylate chemistry. The matting effect is a result of proper combination of waxes and micronized silica. **Coating 1** has the best appearance and properties when applied at 8 µm coating thickness. The major disadvantage of this coating is that gloss must be controlled in quite a limited thickness range. The matting effect is drastically lowered when coating is applied at higher thickness. Thus, a coating thickness of 11 µm produces gloss of 25 gloss units. Bringing the gloss down to 5 or lower requires addition of substantial amount of matting agents and the overall coating properties get worse. The gloss dependency trend limits the application of this coating to smooth non textured keyboard keys. **Coating 1** is a commercialized product and used in the keyboard industry.

Coating 2 is a cost effective coating developed for a broad spectrum of keyboard materials and textures. The gloss is relatively easy to adjust without altering the overall coating performance, making this coating applicable to different substrate finishes at various coating thicknesses. The overall coating properties are achieved by incorporating treated silica with 6 µm average particle size into multifunctional acrylates based formulation. Due to the size of matting particles, the coated surface is somewhat compromised. Yet, at 12 µm dry film coating thickness we could produce acceptable smooth finish.

Coating 3 is a product based on self-matting resins and is quite universal in regards to coated material. As discussed before the tested self-matting resins do not produce finish with gloss of 3-5 units when used by themselves. Further gloss reduction is attained with the help of silica particles. The amount of silica is much lower in comparison to that used in **Coating 2**. This particular formulation uses only 1% silica particles and desired gloss is achieved at 15 µm. The gloss is easy to control which makes the coating suitable to different materials and colors.

Table 2. Coating properties

	Coating 1	**Coating 2**	**Coating 3**
Adhesion[a]	100%	100%	100%
Gloss[b]	5	3	3
Coating Thickness[c], µm	8	12	15
Legend Test[d]	pass	pass	pass
Wear Resistance[d]	>250,000	250,000	250,000
RCA[e]	>150	150	150
Pencil Hardness[f]	1 H	1 H	1 H
Steel Wool Scratch[g], psi	24	32	5

[a] ASTM D-3359
[b] ASTM D 523
[c] Measured with micrometer
[d] Described earlier
[e] ASTM F-2357
[f] ASTM D 3363 750g load, Mitsu-Bishi Hi Uni pencils, ABS
[g] Rotary test representing scratching using #0000 steel wool pad at load @5 rotations. (No scratches at load) – PC data

Antimicrobial surfaces gain more and more popularity in various industries and applications. Computer keyboards harbor harmful bacteria for extended periods[8]. Taking into consideration the magnitude of computer use the bacterial contamination can become a health threatening issue. The mechanism of antimicrobial action is achieved by various antimicrobial agents, such as silver and copper containing compounds, quaternary ammonium compounds, etc[9]. We have incorporated into the UV curable anti-glare coating formulation described above several agents known to suppress the microbial growth. Satisfactory results are achieved with a silver containing compounds in concentration of only 0.2%. **Table 3** demonstrates the antimicrobial effect of Coatings **AB 1, AB 2 and AB 3** against *Staphylococcus aureus* and *Escherichia coli*. The test is performed in accordance to JIS 2801.

Table 3. Anti-Microbial effect against *Staphylococcus aureus* and *Escherichia coli*.

	Escherichia coli			***Staphylococcus areus***			Antimicrobia efficacy against blank) Reduction %
	Number of living bacteria		Antimicrobial activity value against blank	Number of living bacteria		Antimicrobial activity value against blank	
	At beginning	After 24 h		At beginning	After 24 h		
Coating AB1 (blank)	1.4 x 10^5	3.0x10^7	--------	1.8x10^5	9.5x10^5	--------	--------
Coating AB1 (0.2%)	1.4 x 10^5	<1x10^2	>5.4	1.8x10^5	<1x10^2	>3.9	>99.9
Coating AB2 (blank)	1.4 x 10^5	3.2x10^7	--------	1.8x10^5	2.8x10^5	--------	--------
Coating AB2 (0.2%)	1.4 x 10^5	<1x10^2	>5.4	1.8x10^5	<1x10^2	>3.4	>99.9
Coating AB3 (blank)	1.4 x 10^5	3.2x10^7	--------	1.8x10^5	2.8x10^5	--------	--------
Coating AB3 (0.2%)	1.4 x 10^5	<1x10^2	>5.5	1.8x10^5	<1x10^2	>3.4	>99.9
Control Uncoated ABS	1.4 x 10^5	3.7x10^7		1.8x10^5	3.7x10^7		

The UV-curable **Coatings 1, 2 and 3** have excellent chemical resistance to household cleaning solutions, hand lotions, and sunscreens. Common foods and drinks such as coffee, Pepsi cola, ketchup and mustard do not stain the coating surface upon contact for over 8 hours. Chemical resistance tests show that the coatings improve significantly the chemical resistance of the uncoated material. **Table 4** shows the results of chemical tests upon contact with common organic solvents, mineral acid and base.

Table 4. Chemical resistance test

Chemical Resistance	**Uncoated ABS**	**Coating 1**	**Coating 2**	**Coating 3**
Gasoline	C	A	A	A
Sodium hydroxide10% (10%)	C	B	A	B
Acetone	C	B	B	B
Methyl Ethyl Ketone	C	B	B	B
Propyl Alcohol	A	A	A	A
Toluene	C	A	A	A
Sulfuric Acid (10%)	A	A	A	A
Ethyl Alcohol	A	A	A	A

A-Superior Resistance, Long Term Contact (>24 hours)

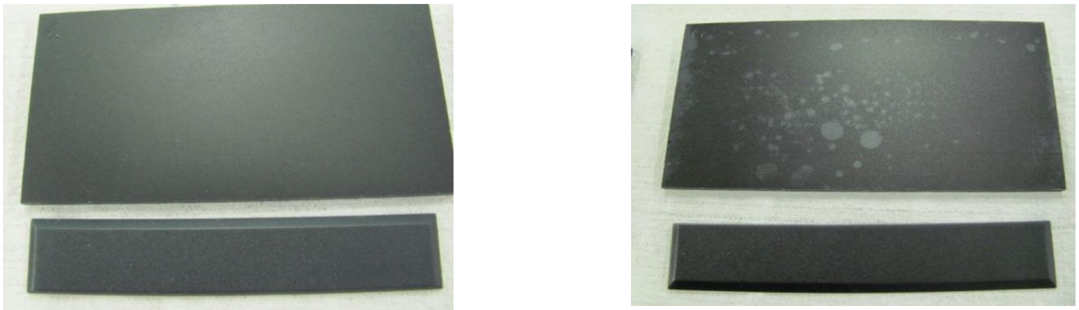
B-Excellent Resistance, Contact up to 8 hours

C-Good Resistance, Contact up to 1 hour

Other Considerations

Solvents and diluents are important ingredients of UV curable coatings applied by spray technique for better flow and leveling[10]. Proper selection of solvent blends is quite a complex process and many factors have to be taken into consideration. Solvency and evaporation rate along with compliance with health, safety and regulatory regulations are key factors in solvent selection. Oxygenated solvents are known to dissolve well acrylic resins. Typically spray application requires at least three types of solvents – fast, medium and slow evaporating. The fast evaporating solvent lowers the initial viscosity and allows for good atomization of the spray. The medium evaporating solvent accounts for controlled release of formulation and prevents dripping and sagging. The slow evaporating solvent is crucial for final flow and leveling of the coating. The solvent blend that has been optimized for the anti-glare coatings contains *n*-butyl acetate, *n*-propyl alcohol, diacetone alcohol and methyl isoamyl ketone. Typical processing parameters for the UV curable anti-glare coatings by spray application include solvents evaporation in a convection recirculating oven for 3 minutes at 35-40°C and UV cure at 460mJ/cm^2 (EIT UVA, Fusion H lamp, 7.6 m/min). These parameters allow for obtaining a smooth coating finish with targeted mechanical properties. However, when IR ovens are used to flash off solvents at 35°C for 3 minutes or longer severe chemical attack on the ABS key surface has been observed. The phenomenon is due to low chemical and temperature resistance of ABS substrate. For application requiring IR assisted flash off of a solvent blend of isobutyl isobutyrate, *n*-propyl alcohol and *n*-butyl alcohol has been proposed.

Both insufficient evaporation of solvents and less UV energy used to cure coatings can lead to “whitening” phenomena, when the coated material is exposed to harsh environmental conditions. The effect is due to leaching of matting agents, surface modifiers and other coating additives that are not chemically bound in the polymer network. **Figure 6** shows the “whitening” issues after the coated material has been exposed to 70°C temperature at 90% humidity for five days. Insufficient flash-off time leads to solvent entrapment within the polymer network. Inadequate UV cure energy results in lower crosslink density and low degree of polymerization. When the recommended processing parameters are followed the whitening issue is eliminated and the coating demonstrates good surface and mechanical properties.



Coating 1 processed within thickness, flash off and UV energy recommended ranges

Coating 1 coated with insufficient UV energy

Figure 6. **Coating 1 after temperature and humidity test**

The overall gloss of a particular coating is influenced by many factors. Material surface finish, spray application conditions, solvent blend evaporation rate, flash off temperatures and UV energy are key factors. One of the most critical factors remains the coating thickness. Dry film thickness of optically clear coatings can be measured easily with instruments analyzing the reflected light. Fast thickness measurement of thin anti-glare coatings, however, remains a challenge. Measurement with micrometer is a common lab and production quality control routine. The reported coating thickness is the difference of the thicknesses of a coated and uncoated substrate. Very often this type of measurement gives misleading values and depends on the surface smoothness, degree of particles wetting and variations in the surface profile. Anti-glare coating thickness can be measured by universal scope tooke gage observation of a precision cut. The V shaped cut, produced by a cutting tip with specific geometry, is observed vertically through the tooke gage microscope with reticle allowing measurement in different units. Both methods give an approximation of coating thickness that might differ significantly from measurements with contemporary microscope techniques.

Summary

New abrasion resistant UV-curable coatings for keyboards have been developed. These low-gloss, thin dry film thickness UV curable coatings, exhibit exceptional chemical resistance, soft feel, and high performance antimicrobial properties. Coated keycaps possess long term wear resistance and maintain the keycap legend integrity and durability under harsh environmental conditions, while ensuring compliance with international health, safety and environmental requirements.

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