
URETHANE-ACRYLIC HYBRID POLYMERS: PERFORMANCE AS 1K COATINGS *

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ABSTRACT

High performance, urethane-acrylic hybrid polymer dispersions have been developed to offer cost/performance advantages over standard 1K coating materials such as polyurethane dispersions (PUDs), acrylic emulsions, and blends thereof. These true hybrid polymers provide many of the benefits (abrasion resistance, superior mechanical properties, chemical resistance) of PUDs but at a cost intermediate between PUDs and low-cost acrylics. An inherent characteristic of a true hybrid is an interpenetrating network (IPN) structure which is indicated by a broad glass transition temperature range. The IPN structure is the result of the chemical composition of the material and, particularly, the process by which the urethane and acrylic are polymerized together as a homogenous mixture which is dispersed as colloidal particles in water. The IPN morphology is apparently responsible for the hybrid's outstanding properties, which would not be predicted from a simple, arithmetic rule of mixtures. Coatings formulated from these hybrid polymers offer a balance of performance similar to a PUD resin.

INTRODUCTION AND BACKGROUND

Thermoplastic polyurethanes are well known for their excellent balance of mechanical toughness and chemical resistance. Unfortunately, the solvent-based versions require exceedingly high levels of VOC for application by conventional coating techniques. The waterborne versions (polyurethane dispersions or PUDs) require significantly lower VOC and are, therefore, becoming increasingly popular choices as binders for a variety of one-component coatings for wood (floors and furniture), plastic (business machine housings), leather, metal, and concrete. Their superior physical and chemical properties have been attributed to a combination of their molecular structure and hard/soft domain morphology.^(1,2)

In general, PUDs are prepared by reacting an excess of diisocyanate with a polyol, dispersing the resultant prepolymer in water, and completing the reaction by adding a water-soluble diamine to consume the residual isocyanate and, thereby, chain-extend the pre-polymer to high molecular weight. The resulting PUD particles are usually anionically stabilized. This is commonly accomplished by incorporating a carboxylic acid-functional polyol into the backbone of the polyurethane and neutralizing the acid groups with a tertiary amine. Thus, in many cases, no external surfactants are present to contribute adversely to water sensitivity of PUD-based coatings.

PUDs are available in both aromatic and aliphatic varieties. The aromatic versions provide better hardness and chemical resistance than their aliphatic counterparts. However, because they

are based on aromatic diisocyanates, the aromatic PUDs are not suitable for applications requiring low yellowing. Therefore, the aliphatic PUDs are required for such cases where exposure to direct or indirect sunlight occurs.

Unfortunately, one of the main disadvantages of the aliphatic PUDs is their relatively high cost. As a result, formulators have sought ways to reduce the cost of their coatings. The most popular strategy is to blend the PUD with an acrylic polymer emulsion that costs less than one-half that of a standard aliphatic PUD. Although the acrylics reduce the system cost, they also reduce the overall performance of the binder. The reduction in performance can be lower than what would be predicted from an arithmetic rule of mixtures.^(3,4) One possible reason for this behavior is that, on a molecular level, the acrylic polymers are not soluble in the polyurethane polymers. Therefore, the polymers remain phase-separated during film formation. Arguably, the resultant phase morphology is at least partly responsible for the diminished performance behavior noted above.

In order to take advantage of the potential cost reduction afforded by the acrylics and maintain a greater share of the advantageous PUD properties, so-called “hybrid” systems were developed. The hybrids incorporate both the urethane and the acrylic polymers into the same dispersion. As outlined in the simplified process flow diagram (Figure 1) below, there are generally 2 methods for preparing the hybrids (Type 1 and Type 2). For Type 1 hybrids, a PUD is first prepared, acrylic monomers are added to the PUD, and the acrylic polymer is formed in the presence of the PUD. To prepare Type 2 hybrids, a polyurethane prepolymer is formed, the acrylic monomers are added to the prepolymer, the mixture is dispersed in water, and the urethane and acrylic polymerizations are completed concurrently.⁽⁵⁾

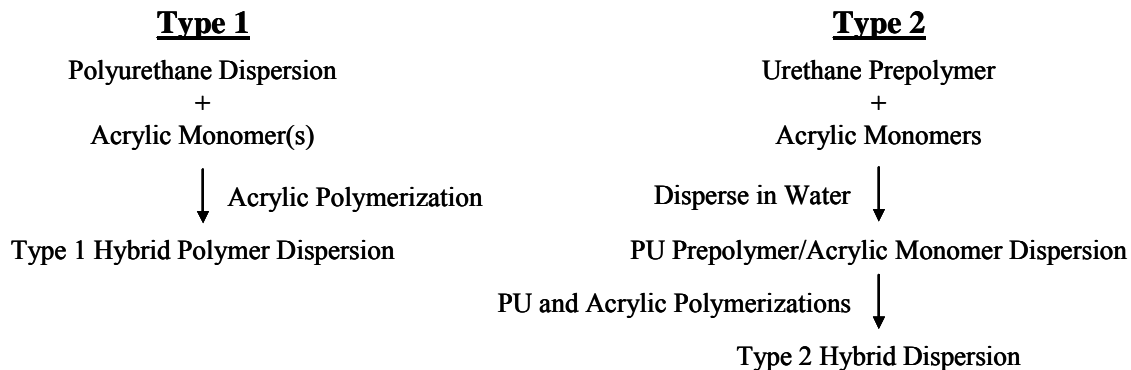


Figure 1: Simplified process flow diagram for preparation of Type 1 and Type 2 hybrids.

The urethane and acrylic polymers in the hybrids exhibit improved molecular compatibility versus simple blending. The improved compatibility is demonstrated by the dynamic mechanical analysis (DMA) data that are shown in Figure 2. The simple blend shows 2 distinct tan delta ($\tan \delta$) peaks, which show the glass transition temperatures (T_g) for the phase-separated urethane and acrylic polymers. The hybrid prepared from the first method described above also shows 2 T_g peaks, but the peaks have become somewhat broader, which is indicative of some limited

molecular mixing. In contrast, a Type 2 hybrid, in which the urethane prepolymer and acrylic monomers are homogeneously mixed prior to dispersion and subsequent polymerization, exhibit only a single, very broad tan δ peak. The single peak, which spans the temperature range between the theoretical T_g s of the urethane and acrylic polymers, is consistent with the explanation of an interpenetrating network (IPN) structure (i. e., a significant amount of polymer-polymer mixing). Presumably, the improved compatibility for the hybrids (especially Type 2) is at least partly the result of some molecular-level grafting of the two polymers.

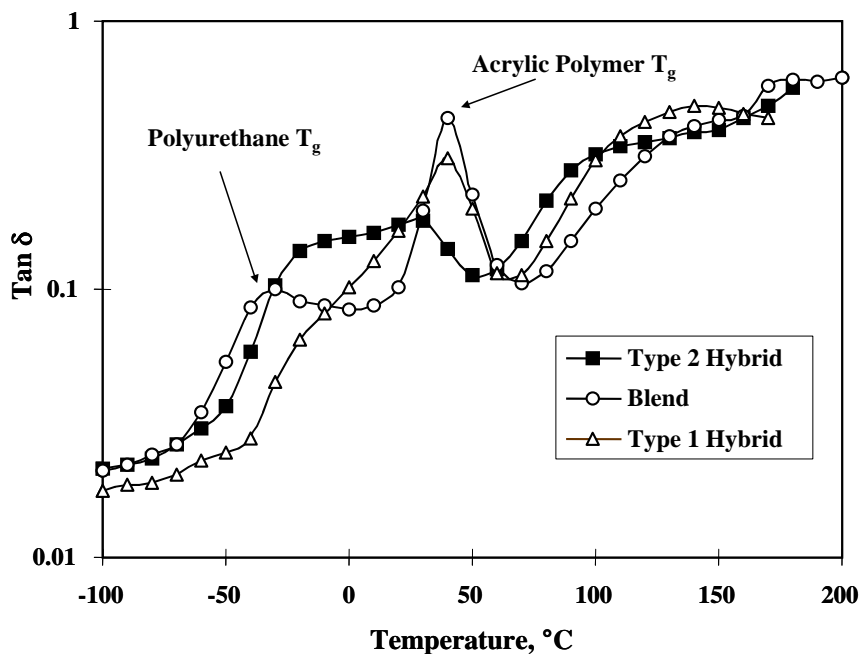


Figure 2: DMA data comparing a simple blend with the hybrids.

As mentioned previously, the rationale for preparing the hybrids was to improve the performance relative to a simple blend. In Figure 3, the tensile strengths of films prepared from the individual

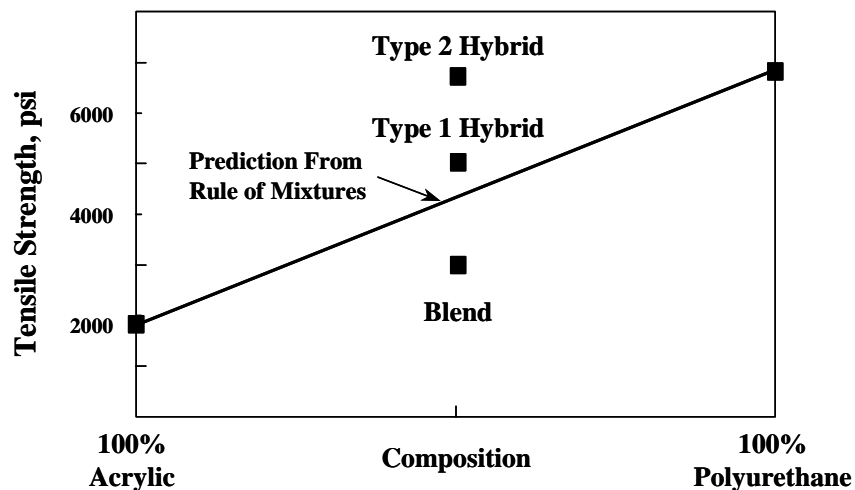


Figure 3: Comparison of the Tensile Strengths of Free Films Prepared from a Simple Blend and the Hybrids.^(3,4)

polymers, a blend, and the 2 hybrid types are compared to that predicted by a linear rule of mixtures. The blend and the hybrids contain equal amounts of the same urethane and acrylic polymers. As expected, the urethane polymer had a significantly higher tensile strength than the acrylic polymer. Interestingly, the tensile strength of the blend was found to be lower than that predicted by the simple averaging-rule. On the other hand, the hybrid systems show higher tensile strengths than predicted. Remarkably, the Type 2 hybrid was found to have a tensile strength approximately equal to that of the polyurethane. Similar results have been reported elsewhere.⁽³⁾ One conclusion is that the phase morphology of an urethane/acrylic polymer system has a significant influence on the ultimate performance.

In this paper, the formulation and performance of one-component (1K) coatings based on Type 2 urethane-acrylic hybrid polymers will be discussed.

EXPERIMENTAL

The typical characteristics of the Type 2 hybrids evaluated in this study are provided in Table 1. Clear and pigmented coating formulations (Appendix A, Tables A1-A6) were prepared using standard techniques. The properties of the formulations are provided in Tables B1-B6 in Appendix B. Coating properties were tested over cold-rolled steel with a zinc phosphate treatment (Bonderite 952) or, for the studies comparing the performance of the crosslinked coatings, untreated cold-rolled steel. The coatings were applied using a #60 wire-wound draw-down rod and were allowed to dry at 21 °C (70 °F) and 50% relative humidity for 7 days. Coating formulation W2, which was prepared using the resin-free pigment dispersion, was applied using conventional air spray. Depending on the formulation, dried film thickness ranged from 30 μm (1.2 mil) to 76 μm (3.0 mil). The standard test methods listed in Table 2 were used to evaluate coating performance.

Table 1: Typical Characteristics of the Type 2 Hybrid Polymers Evaluated

Property	Hybrid 1 ^a	Hybrid 2 ^b
Appearance	Milky White	Milky White
Brookfield Viscosity, cP, 25 °C	50 - 150	50 - 150
Non-Volatiles, % by weight	39 - 41	39 - 41
Solvent ^c Content, % by weight	6	6
VOC, g/L (lbs/gal)	150 (1.3)	150 (1.3)
Density, g/mL (lbs/gal)	1.1 (8.6)	1.1 (8.7)
pH	7.5 – 9.0	7.5 – 9.0
Approximate T _g Range ^d , °C	-35 to 35	-35 to 100
Particle Size, nm	80 – 110	80 - 110
Particle Charge	Anionic	Anionic
^a HYBRIDUR [®] 570 Polymer Dispersion, Air Products and Chemicals, Inc. ^b HYBRIDUR [®] 580 Polymer Dispersion, Air Products and Chemicals, Inc. ^c Solvent: N-methylpyrrolidinone (NMP) ^d As estimated from DMA measurements (breadth of tan δ peak).		

Table 2: Test Methods Used to Evaluate the Performance Characteristics of the Coatings

Property	ASTM Test Procedure
Adhesion, Dry and Wet Tape	D 3359
Dry Time	D 5895
Flexibility (Mandrel Bend)	D 1737
Gloss	D 523
Hardness (Persoz)	D 4366
Humidity Resistance (Cleveland)	D 2247
Immersion Resistance	D 870
Impact Resistance	D 2794
Salt Spray	B 117, D 1654, D 714
Solvent Resistance (Double Rubs)	D 4752

DMA data was obtained on neat resin coatings (i. e., unformulated) using a Rheometrics solids analyzer (RSA II) in a tensile dynamic mode with a thin film fixture. The films were analyzed over the temperature range from $-150\text{ }^{\circ}\text{C}$ to $250\text{ }^{\circ}\text{C}$. The samples were not preconditioned with regard to humidity prior to data acquisition, but dry nitrogen was used as the atmosphere during the measurements. Data was acquired at intervals of $6\text{ }^{\circ}\text{C}$; a one-minute soak time was used at each measurement temperature to ensure isothermal equilibration.

RESULTS AND DISCUSSION

Type 2 Hybrid Polymers

Hybrid 1 was the primary polymer dispersion chosen for study, since it has proven to be a versatile material for use in a wide variety of applications. In the clear coatings (C1 and CX1) where it is utilized as a blend with Hybrid 1, Hybrid 2 has been found to improve the film hardness compared to the Hybrid 1 coatings. The increase in film hardness is most likely because the T_g for Hybrid 2 covers a significantly wider and higher temperature range than that for Hybrid 1. Thus, at the measurement temperature ($21\text{ }^{\circ}\text{C}$), a greater percentage of the polymer mixture exists in a hard, glassy state. For this series, formulations containing only Hybrid 2 provide maximum hardness. The improvement in hardness achieved in this way illustrates one of the hybrid technology features - the ability to blend hybrids with various physio-chemical characteristics to potentially achieve desired performance attributes.

Clear Coatings C1 and CX1

As mentioned above, the clear coatings tested here contained a blend of the relatively soft Hybrid 1 and the harder Hybrid 2. The properties of these coatings are given in Table 3. The clear coatings show good adhesion, high gloss, fast dry times, superior impact resistance, and overall good solvent resistance. The fast dry times allow for relatively high productivity or rapid return to service for applications where these coatings are used. These coatings exhibit high gloss and outstanding clarity; which makes them suitable for coatings used, for example, on ornamental objects. Also, as mentioned previously, similar formulations using only Hybrid 2 have improved

hardness and good abrasion resistance and, therefore, are potentially useful as protective topcoats on certain types of epoxy coatings (e. g., waterborne epoxy floor coatings).

Table 3: Properties of Clear Coatings – Un-Crosslinked (C1) and Crosslinked (CX1)

Property	C1	CX1
Adhesion Dry Tape	5A	5A
Wet Tape (24 hr @ 21 °C)	5A	5A
Wet Tape (100 hr @ 21 °C)	---	5B
Dry Time (Dry Hard), minutes	24	< 30
Gloss, 60°	97	> 95
Hardness (Persoz), s	165	129
Immersion Resistance, water (24 hr @ 21 °C)	no effect	no effect
Impact Resistance, in-lb	> 160	> 160
Solvent Double Rubs 2-Propanol (IPA)	110	190
Toluene	200	200
2-Butanone (MEK)	200	200

One weakness of the un-crosslinked clear coating is its IPA resistance. However, the IPA resistance was significantly improved through the use of an epoxy-silane crosslinker. Despite the crosslinking, the coating still maintained its flexibility. Interestingly, the crosslinked coating appeared to be somewhat softer; the reason for the softer film is not immediately obvious. The chemistry of the crosslinker will be discussed in more detail in a subsequent sub-section.

Pigmented White Coatings W1, WX1, and W2

The properties of these coatings are provided in Table 4. Similar to that for the clear coatings,

Table 4: Properties of Pigmented White Coatings – Un-Crosslinked (W1, W2), Crosslinked (WX1), and Prepared Using a Resin-Free Pigment Dispersion (W2)

Property	W1	WX1	W2
Adhesion Dry Tape	5A	5A	5A
Wet Tape (24 hr @ 21 °C)	5A	5A	4A
Dry Time (Dry Hard), minutes	< 30	< 30	40
Gloss, 60°	60 - 70	60 - 65	75 – 80
Hardness (Persoz), s	148	106	112
Impact Resistance, in-lb	> 160	> 160	> 160
Solvent Double Rubs IPA	100	180	---
Toluene	> 100	200	200
MEK	> 100	200	200

the pigmented coatings exhibited dry rapidly, good adhesion, outstanding impact resistance, and good resistance to toluene and MEK. Again, the resistance to IPA was relative low, but that was improved by crosslinking.

Also, it was observed that the gloss of the pigmented coatings was somewhat lower than the clear coatings. This was most likely due to relatively poor pigment wetting, since the hybrids do not contain external surfactants that could serve as pigment wetting agents. Formulation W2 was developed to overcome that deficiency. Using an efficient pigment wetting agent, a resin-free pigment grind was used to ensure adequate pigment dispersion and stabilization. Thus, a gloss of 75 – 80 (~10 – 20 units higher than that for W1 or WX1) was obtained for the W2 formulation. In addition, the W2 formulation can also be modified by the addition of the epoxy-silane crosslinker to improve the IPA resistance.

White Primer Coating P1

The properties of the primer coating are shown in Table 5.

Table 5: Properties of White Primer Coating (P1)

Property	P1
Adhesion Dry Tape	5A
Wet Tape (24 hr @ 21 °C)	5A
Wet Tape (260 hr Humidity Test)	5B
Dry Time (Dry Hard), minutes	< 30
Gloss, 60°	28 - 32
Hardness (Persoz), s	55
Immersion Resistance, Water (24 hr @ 21 °C)	no effect
Immersion Resistance, Hydraulic Fluid (24 hr @ 66 °C)	no effect
Impact Resistance, in-lb	> 160
Salt Spray, hours with no effect	
Sand-Blasted Steel	> 500 ^a
Iron-Phosphated Steel (Bonderite 1000)	> 500
Untreated Cold-Rolled Steel	> 260
Solvent Double Rubs Toluene	> 200
MEK	> 200
^a 8F blisters in the field.	

The primer formulation showed good corrosion resistance – more than 500 hours on the iron phosphated and the sand-blasted steel substrates and over 260 hours on untreated steel. Additionally, the high impact resistance showed that the coating was extremely flexible. Furthermore, the coating exhibited adequate adhesion, immersion resistance, and solvent resistance. As with all of the coatings tested, the dry time for this formulation was < 30 minutes at room temperature. The fast dry time suggests that this primer would be useful for applications

that require rapid turn-around of the coated materials. For a 1K coating, the primer coating displayed an excellent overall balance of properties.

Crosslinking

A number of crosslinking chemistries are known for PUDs. Table 6 provides a summary of these chemistries and their attributes.

Table 6: Crosslinker Chemistries and Their Attributes

Crosslinker Chemistry	Attributes
Polyaziridines	Toxicity; Limited Shelf Life
Carbodiimides	Heat Cure
Water Dispersible Isocyanates	2K; Limited Pot Life
Waterborne / Dispersible Epoxies	2K; Long Pot Life
Metal Salts (Zn^{2+} , Zr^{4+})	2-Component (2K)
MF/UF Resins	Heat Cure
γ -Glycidoxypropyltrimethoxysilane	2K; Short Pot Life
β -(3,4-Epoxy-cyclohexyl)ethyltriethoxysilane)	1K

With the exception of the last chemistry listed on the table, all of the other crosslinking chemistries do not provide a true 1K system. Because it was desired to keep all of the formulations 1K systems, the β -(3,4-epoxy-cyclohexyl)ethyltriethoxysilane) was chosen for crosslinking this system. As discussed previously, this crosslinker provided improved solvent resistance to the systems. The formulation has been found to be shelf stable for at least 6 months without noticeable changes in viscosity or performance.⁽⁶⁾

Aspects of the chemistry of this crosslinker have been described previously.^(7,8) In the present case, crosslinking of the hybrid polymer is accomplished through several reaction steps. Since the epoxy-silane is added directly to the water phase, one step involves the hydrolysis of the alkoxy groups and subsequent condensation of the resulting silanol groups between epoxy-silane molecules. This reaction leads to molecules that are essentially multifunctional epoxies; the multifunctionality is necessary for crosslinking. The hydrolysis reaction occurs slowly over several days, and that necessitates the need for the formulation to “sweat-in” for at least 4 days prior to application. Another reaction is that of the epoxy groups with the carboxylic acid groups on the polyurethane backbone. This reaction will occur slowly at room temperature as the free carboxylic acid groups are regenerated after the neutralizing amine has evaporated during film formation. Despite the presence of neutralizing amine and the resultant high pH (7.5 – 9.0) of these systems, storage stability is greater than for conventional glycidyl ether epoxies because of the relatively low reactivity of the cycloaliphatic epoxy group to amines. On the other hand, cycloaliphatic epoxy groups are comparatively more reactive to carboxylic acids, so that enhances the reaction with the backbone carboxylic acid groups.

SUMMARY AND CONCLUSIONS

Waterborne, high performance, urethane-acrylic hybrid polymer dispersions have been developed to offer cost/performance advantages over standard 1K coating materials such as polyurethane dispersions (PUDs), acrylic emulsions, and blends thereof. These so-called Type 2 hybrid polymers provide many of the benefits (e. g., superior mechanical properties and chemical resistance) of PUDs but at a cost intermediate between PUDs and low-cost acrylics. The Type 2 hybrid has an interpenetrating network (IPN) polymer structure which is denoted by a broad glass transition temperature range as measured by DMA. The IPN structure is the result of the chemical composition of the material and, particularly, the process by which the urethane and acrylic are polymerized together as a homogenous mixture which is dispersed as colloidal particles in water. The IPN morphology is apparently responsible for the hybrid's outstanding properties, which would not be predicted from a simple, arithmetic rule of mixtures. Coatings formulated from these Type 2 hybrids show an outstanding balance of physical (e. g., high impact resistance) and chemical (e. g., solvent resistance) performance for 1K systems. Performance (e. g., IPA resistance) of these systems can be further enhanced and a 1K system maintained through crosslinking by a cycloaliphatic epoxy-silane.

ACKNOWLEDGMENTS

Many people have contributed over the years to the development of the hybrid technology, and the authors extend their gratitude to all of them. Special mention and thanks must be made to Dr. Dick Derby who, through his pioneering spirit, perseverance and advice, has made the most significant contributions through the years. Many thanks to: Dr. Bruce Gruber for his work in the field of hybrid synthesis; Dr. Menas Vratsanos for his DMA work; and Julie Baum for providing the motivation for the writing of this paper.

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APPENDIX A: Coating Formulations (See Appendix C for list of materials and suppliers.)

Table A1: Clear Coating Formulation C1

Material	Pounds	Gallons
Pre-Mix: <i>Mix a solution of the following.</i>		
Solvent ^a	82.45	10.86
Surfactant ^b	3.72	0.45
Light Stabilizer ^c	6.25	0.71
Light Stabilizer ^d	3.13	0.37
Resin Blend: <i>Add to the following with agitation.</i>		
Hybrid Polymer Dispersion 1 ^e	435.33	50.65
Hybrid Polymer Dispersion 2 ^f	186.53	21.70
Defoamer Blend: <i>Add and stir for 20 minutes.</i>		
Defoamer ^g	1.77	0.21
Letdown: <i>Dilute to brush and roll viscosity.</i>		
Water	125.62	15.05
Total	844.80	100.00

Table A2: Pigmented Semi-Gloss White Coating Formulation W1

Material	Pounds	Gallons
Grind: <i>Add the following into a clean container under mild agitation and mix until blended.</i>		
Hybrid Polymer Dispersion 1 ^e	111.40	12.96
Surfactant ^h	2.24	0.25
Surfactant ¹	2.24	0.26
Defoamer ^j	1.42	0.19
TiO ₂ Pigment ^k	217.61	6.53
<i>Grind the pigments using a media mill or a ball mill. Temperature must not exceed 140 °F.</i>		
Letdown: <i>Add the following to the grind; mix with medium agitation for a minimum of 15 minutes.</i>		
Hybrid Polymer Dispersion 1 ^e	602.99	70.15
Solvent ¹	19.13	2.41
Ammonium Benzoate ¹	36.42	4.36
Light Stabilizer ^{d,2}	14.34	1.75
Light Stabilizer ^{c,2}	9.56	1.14
Total	1017.35	100.00
¹ Added to the letdown as a 10% solution in water (included in weight).		
² 50% solution in solvent. ^s		

Table A3: Pigmented Gloss White Coating Formulation W2

Material	Pounds	Gallons
Resin-Free Grind: Add the following into a clean container and mix under mild agitation until blended.		
Water (Deionized)	23.79	2.85
Pigment Dispersant ^m	28.22	3.20
Defoamer ⁿ	0.62	0.08
<i>Continue agitation while adding the pigment below.</i>		
TiO ₂ Pigment ^o	235.31	7.06
<i>Increase speed to high and disperse to Hegman ≥ 7 grind. Temperature must not exceed 140 °F.</i>		
<i>Reduce speed and add the following with medium agitation until blended.</i>		
Water (Deionized)	20.91	2.51
Blend: Add the following into a separate, clean container under mild agitation and mix until blended.		
Hybrid Polymer Dispersion 1 ^e	686.68	79.89
<i>Pre-blend the next 4 items before adding to the HYBRIDUR 570 Dispersion.</i>		
Surfactant ^b	1.34	0.16
Solvent ^p	17.20	2.26
Solvent ^l	15.45	1.95
Defoamer ^g	0.31	0.04
Final Blend: Slowly add the resin-free grind to the blend and mix with mild agitation until homogeneous.		
Total	1029.83	100.00

Table A4: Clear Crosslinking Coating Formulation CX1

Material	Pounds	Gallons
Pre-Mix: Mix a solution of the following.		
Solvent ^q	79.99	10.53
Surfactant ^b	3.63	0.44
Light Stabilizer ^c	6.08	0.69
Light Stabilizer ^d	3.04	0.36
Resin Blend: Add to the following with agitation.		
Hybrid Polymer Dispersion 1 ^e	421.97	49.09
Hybrid Polymer Dispersion 2 ^f	180.83	21.04
Defoamer Blend: Add and stir for 20 minutes.		
Defoamer ^g	1.69	0.20
Letdown: Dilute to brush and roll viscosity.		
Water	122.81	14.72
Crosslinker: Add and stir for 20 minutes.		
Crosslinker ^f	24.58	2.93
Total	844.62	100.00

NOTE: Allow a sweat-in period of at least 4 days prior to use of the formulation.

Table A5: Pigmented Semi-Gloss White Crosslinking Coating Formulation WX1

Material	Pounds	Gallons
Grind: Add the following into a clean container under mild agitation and mix until blended.		
Hybrid Polymer 1 ^e	297.73	34.64
Surfactant ^h	2.23	0.25
Surfactant ¹	2.23	0.26
Defoamer ^j	1.42	0.18
TiO ₂ Pigment ^k	214.04	6.42
<i>Grind the pigments using a media mill or a ball mill. Temperature must not exceed 140 °F.</i>		
Letdown: Add the following to the grind; mix with medium agitation for a minimum of 15 minutes.		
Hybrid Polymer 1 ^e	404.34	47.04
Solvent ^l	18.77	2.37
Ammonium Benzoate ¹	34.69	4.15
Solvent ^s	12.07	1.51
Light Stabilizer ^d	7.10	0.85
Light Stabilizer ^c	4.77	0.54
Crosslinker ^r	15.01	1.79
Total	1014.40	100.00
¹ Added to the letdown as a 10% solution in water (included in weight).		

NOTE: Allow a sweat-in period of at least 4 days prior to use of the formulation.

Table A6: White Primer Formulation P1

Material	Pounds	Gallons
Grind: Add the following into a clean container under mild agitation and mix until blended.		
Hybrid Polymer Dispersion 1 ^e	137.38	15.98
Pigment Dispersant ^m	9.12	1.04
Defoamer ^j	3.67	0.48
TI-PURE [®] R960 ^k	68.59	2.06
Anticorrosive Pigment ^t	119.84	3.78
<i>Increase speed to high and disperse to Hegman ≥ 7 grind. Temperature must not exceed 140 °F.</i>		
Letdown: Add the following to the grind; mix with medium agitation for a minimum of 15 minutes.		
Hybrid Polymer Dispersion 1 ^e	552.61	64.29
Associative Thickener ^{u,1}	0.89	0.11
Surfactant ^{v,1}	4.56	0.59
Ammonium Benzoate ²	39.65	4.74
Solvent ^l	54.91	6.93
Total	991.22	100.00
¹ Preblend these 2 components before adding to the letdown.		
² Added to the letdown as a 10% solution in water (included in weight).		

APPENDIX B: Coating Formulation Properties

Table B1: Properties of the Clear Coating Formulation C1

Weight Solids, %	32.7	PVC, %	0
Volume Solids, %	30.2	VOC, lb/gal (g/L)	2.77 (332)

Table B2: Properties of the Pigmented Semi-Gloss White Coating Formulation W1

Weight Solids, %	54.5	PVC, %	15.0
Volume Solids, %	45.6	VOC, lb/gal (g/L)	1.40 (168)
Viscosity, s, Ford #4	24	Density, lb/gal (g/mL)	12.10 (1.45)

Table B3: Properties of the Pigmented Gloss White Coating Formulation W2

Weight Solids, %	52.4	PVC, %	17.1
Volume Solids, %	41.2	VOC, lb/gal (g/L)	1.66 (199)
Viscosity, cP	500	Density, lb/gal (g/mL)	10.26 (1.23)

Table B4: Properties of the Clear Crosslinking Coating Formulation CX1

Weight Solids, %	32.7	PVC, %	0
Volume Solids, %	30.2	VOC, lb/gal (g/L)	2.77 (332)

Table B5: Properties of the Pigmented Semi-Gloss White Crosslinking Coating Formulation WX1

Weight Solids, %	54.5	PVC, %	15.0
Volume Solids, %	45.6	VOC, lb/gal (g/L)	1.40 (168)
Viscosity, s, Ford #4	24	Density, lb/gal (g/mL)	12.10 (1.45)

Table B6: Properties of the White Primer Formulation P1

Weight Solids, %	50.2	PVC, %	15.5
Volume Solids, %	40.7	VOC, lb/gal (g/L)	1.89 (227)
Viscosity, cP	500	Density, lb/gal (g/mL)	9.91 (1.19)

APPENDIX C: List of Materials and Suppliers

Superscript	Material	Supplier
a	ARCOSOLV [®] DPNB	Lyondell
b	BYK [®] -346	Byk-Chemie
c	TINUVIN [®] 384 Light Stabiliser	Ciba Specialty Chemicals
d	TINUVIN [®] 292 Light Stabiliser	Ciba Specialty Chemicals
e	HYBRIDUR [®] 570 Polymer Dispersion	Air Products
f	HYBRIDUR [®] 580 Polymer Dispersion	Air Products
g	SURFYNOL [®] DF-58 Defoamer	Air Products
h	AEROSOL [®] OT 75% Surfactant	Cytec
i	SURFYNOL [®] 465 Surfactant	Air Products
j	FOAMASTER [®] VF	Cognis
k	TI-PURE [®] R960	DuPont
l	TEXANOL [®] Ester Alcohol	Eastman
m	Disperbyk [®] -190	Byk-Chemie
n	DEE FO [®] PI-4	Ultra Additives
o	TI-PURE [®] R706	Dupont
p	DOWANOL [®] DPnB	Dow Chemical
q	ARCOSOLV [®] DPNB	Lyondell
r	CoatOSil [®] 1770 Silane	Witco
s	ARCOSOLV [®] TPM	Lyondell
t	HEUCOPHOS [®] ZBZ	Heubach
u	TAFIGEL [®] PUR 60 Thickener	Münzing Chemie
v	BYK [®] -348	Byk-Chemie