CYCLOALIPHATIC EPOXIDE RESINS FOR CATIONIC UV-CURE

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ABSTRACT

This paper introduces the cyclo – aliphatic epoxide resins used for the various applications of radiation curing and their comparison with acrylate chemistry. Radiation curable coatings and inks are pre – dominantly based on acrylate chemistry but over the last few years, cationic chemistry has emerged successfully[1] with the unique properties inherent with cyclo – aliphatic epoxide ring structures. Wide variety of cationic resins and diluents, the formulation techniques to achieve the desired properties greatly contributes to the advancement of UV – curing technology.

INTRODUCTION

UV cationic cure[2,3] is recognized for outstanding adhesion to difficult substrates. This can be attributed to low shrinkage of epoxy resin systems cured via a cationic mechanism. Another beneficial feature of UV cationic chemistry is the absence of oxygen inhibition. Cycloaliphatic epoxide resins may comprise some 70 % of a typical commercial formulation. Other commonly used components include hydroxy or epoxy functional oils, and vinyl ethers and esters.

Photoinitiators used in these chemical systems are typically aryl sulfonium salts, but iodonium salts are also used, both with a variety of counterions. On irradiation with ultraviolet light these photoinitiators generate strong acids which cause a rapid ring – opening whereby cycloaliphatic epoxides cross link with each other and also with hydroxyl compounds, if these are present. Additives such as fillers, pigments, and slip agents are also commonly used.

This chemistry affords some important benefits for special requirements. In addition to providing excellent adhesion to metals, polyolefins and other plastics, cationic epoxy based chemistry may offer benefits of lower shrinkage on curing, good flexibility, low odor in the formulation and cured film, low toxicity and skin irritation, no oxygen inhibition , improved gas barrier properties, good electrical properties, and high chemical and solvent resistance. Epoxide resin systems cured by a cationic mechanism continue to propagate after the removal of the radiation source, which contributes to good through cure. After UV exposure, heating will also cause additional polymerization.

CATIONIC CURE TECHNOLOGY

General background

Both cationic and free – radical cure systems can be initiated by UV light sources. Both require photoinitiators and can utilize photosensitizers. Formulations in each category contain polymerizable components and additives. There are, however, significant differences between the two systems. Of greatest significance, the photoinitiators are chemically different. Also, cured film properties of cationic systems are improved by a post – cure thermal treatment. This can be a disadvantage or an advantage, depending on the end – use.

Photointiator systems

Cationic photoinitiators may consist of onium salts, ferrocenium salts, or diazonium salts.

UV cationic polymerization of cycloaliphatic epoxy resins results from generation of a strong acid[4]. A typical photoinitiator activation mechanism is shown in Fig.1. The polymerization of the epoxy monomer proceeds (initiation, chain reaction) as shown in Fig.2 and 3 respectively, via a ring – opening of the epoxy moiety to form a reactive cationic species which attacks and opens the next epoxide monomer.

$$Ar_3S^+X^- \xrightarrow{h\nu} [\ Ar_3S^+X^-\ ]^*$$

$$\nearrow\ Ar_2S + Ar^+X^- \xrightarrow{RH} Ar_2S + ArR + \underline{HX}$$

$$\searrow\ Ar_2S^{+\bullet} + Ar^{\bullet}X^- \xrightarrow{RH} Ar_2S + ArR + \underline{HX}$$

X = counterion (PF_6^- or SbF_6^-)

Fig.1. Typical Photoinitiator Activation

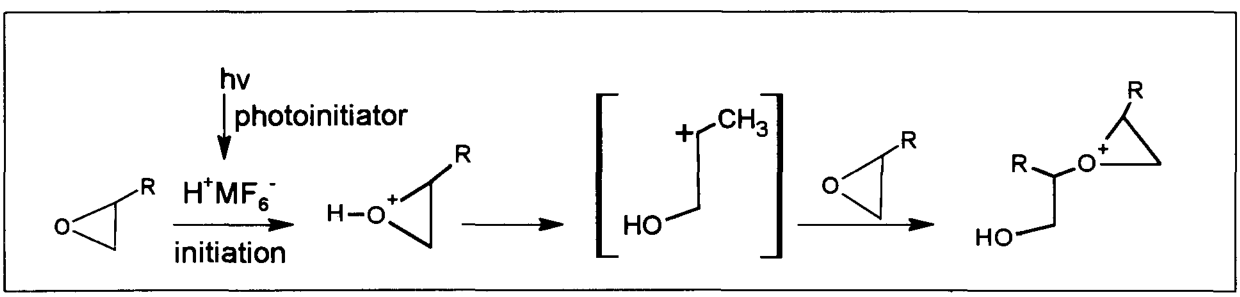

Fig.2. Initiation

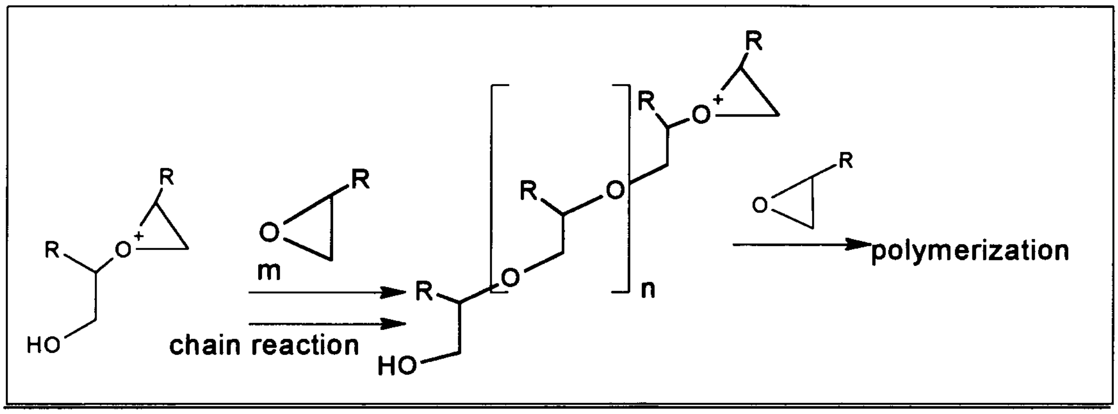

Fig.3. Chain Reaction

Chain transfer (Fig. 4) can occur, for example with hydroxyl functional materials. Chain termination can occur by neutralization of the cationic species by an anionic species (Fig.5)

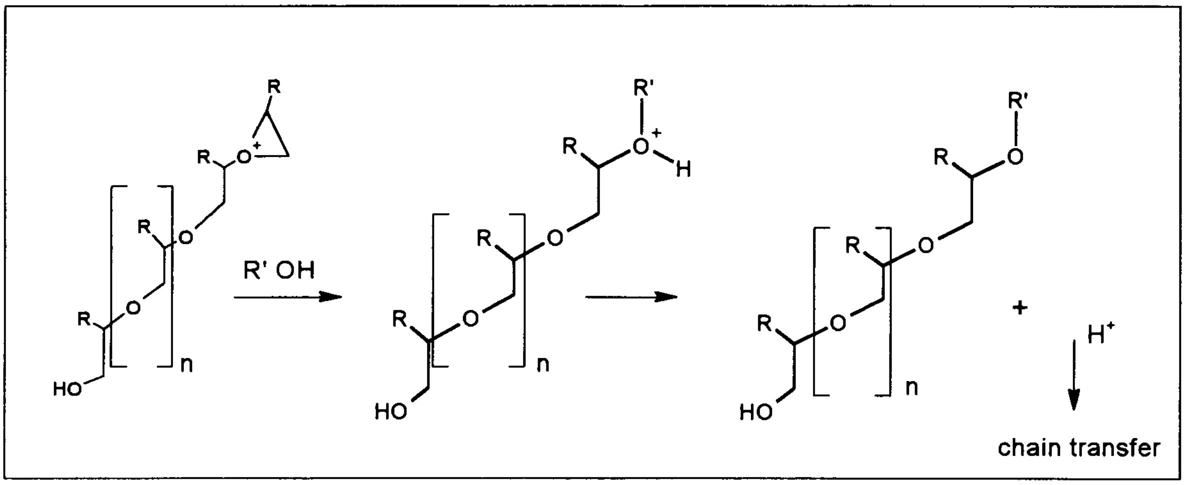

Fig.4. Chain Transfer

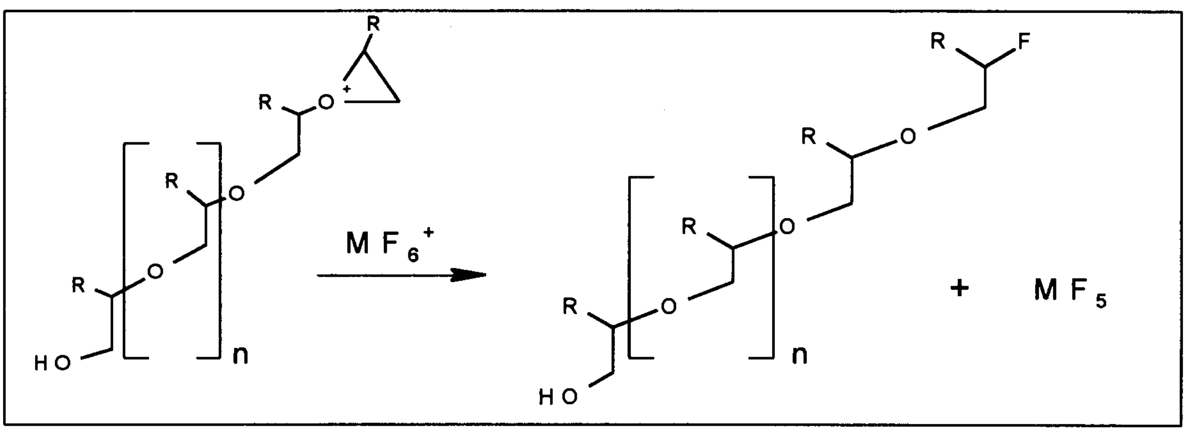

Fig.5. Chain Termination

The cationic initiation step is begun by incident light radiation, and to a lesser extent, by heat. The chain reaction is typically accelerated by addition of heat to the reaction mixture. Chain transfer and termination steps are also promoted by heat addition, however the termination step is also a function of the nucleophilicity of the anionic species.

Comparisons to Free radical Systems

Table I summarize the major differences between cationic and free- radical cure UV systems.

Table I: Radcure Chemistry – Free Radical vs. Cationic

Feature	Free Radical	Cationic
Cure Speed	High	Moderate to high
Initiation	Light	Light to heat
Oxygen sensitivity	Yes	No
Shrinkage	Large	Negligible
Adhesion	Moderate to good	Excellent
Post Cure	Limited Effect	Strong effect
Chemical Resistance	Good	Moderate to good
Humidity Resistance	No	Yes
Acid / Base sensitivity	No	Yes

The benefits of no oxygen inhibition are that the formulator can use lower photoinitiator concentration for the same cure speed or to obtain less residual odor and extractables.

Reduced shrinkage provides better adhesion and other advantages to the end user (e.g. reduced curl on paper or films).

The dark and thermal post- cure effect of cationic systems means that cure can be delayed after exposure, such that non – transparent substrates can be laminated.

Both cationic and free – radical systems have typically high chemical and solvent resistance, good impact resistance and flexibility, high gloss, and are useful in 100 % solids systems.

The base sensitivity of cationic systems requires extra caution in formulating to avoid bases such as amines, urethanes, basic pigments or fillers. To avoid possible base contamination, dedicated equipment may be desirable. Moisture sensitivity dictates that controlled humidity is desirable, as water is a chain transfer agent. Cationic systems are also sensitive to substrate characteristics. The wrong substrate can totally inhibit cure.

Also, acidity can cause viscosity build of cationic formulations. Thermal post – cure is necessary for quick development of properties. For temperature sensitive substrates, this may be a disadvantage. Cured products may also contain residual acids from photoinitiator decomposition.

·UVACURE PRODUCTS

Cycloaliphatic Epoxide Resins

Uvacure 1500

Uvacure 1500 is a very pure grade of 3,4 – epoxycyclohexyl – methyl – 3,4 – epoxycyclohexane carboxylate.

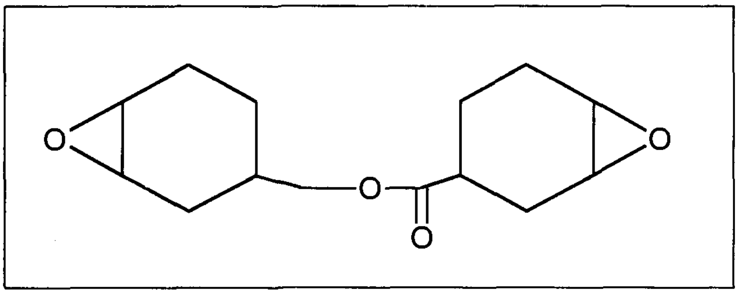

Fig.6.Uvacure 1500

Coatings containing this resin can possess excellent toughness, solvent resistance, and good adhesion to a variety of substrates. Uvacure 1500 is used in metal container decoration, plastic coatings, conformal coatings, UV Inks for component markings, flexography, laminating and assembly adhesives, potting and encapsulating compounds and a variety of other applications. This and other cycloaliphatic epoxide resin are listed in Table II

Table II: Cycloaliphatic Epoxide Resins

Uvacure	Description	Comments
1500	Base cycloaliphatic di – epoxide	Primary component of cationic curing formulations
1501	Cycloaliphatic di – epoxide for applications requiring lower residual odor	Reduces or eliminates the odor emitted by sulfonium salt photoinitiators
1502	Lower viscosity epoxide for exceptionally fast cure with greater formulating latitude	Spray applications, diluent for lower viscosity formulations

Modified Cycloaliphatic Epoxides

Uvacure Modified Cycloaliphatic Epoxides are designed to provide properties not achievable with conventional cycloaliphatic epoxides. See Table III. Benefits of this class of materials include enhanced flexibility, improved toughness, and better chemical resistance of cured films containing these materials. These products may offer even higher cure response, reduced susceptibility to atmospheric humidity, and better adhesion. All polyol blends have superior film forming properties.

Table III: Modified Cycloaliphatic Epoxides

Uvacure	Description	Comments
1530	Epoxide / aliphatic polyol blend with low weight per epoxide (184) , weight per hydroxyl (370)	High cure speed, strength , hardness, solvent resistance and crosslink density
1531	Epoxide / aliphatic polyol blend with medium weight per epoxide (227) , weight per hydroxyl (446)	Good strength , excellent toughness and flexibility
1532	Epoxide / aliphatic polyol blend with high Weight per epoxide (273), weight per hydroxyl (555)	Softer film and higher flexibility
1533	Modified cycloaliphatic epoxide with weight per epoxide of 262	Soft, flexible, exceptional adhesion in coatings and laminating adhesives
1534	Modified cycloaliphatic epoxide with weight per epoxide of 268 , weight per hydroxyl of 375	Good water resistance , flexibility and toughness for metal varnish, coatings on wood, paper, metals, plastics, etc.

Hybrid Resin Systems

Uvacure Hybrid Resin Systems are designed to cure via a hybrid mechanism, that is, by a combination of cationic and free- radical mechanisms under UV light. Typical benefits include 1) increased cure speed 2) faster development of final properties, 3) lower sensitivity to moisture and other cationic inhibitors, 4) improved film forming properties, and 5) wider formulating latitude. Hybrid Resin systems may be particularly desirable for improved compatibility with pure cationic, or pure free – radical coatings and inks. For example, a hybrid OPV may be more compatible with a free – radical ink than would a cationic OPV. These products are listed in Table IV.

Table IV: Hybrid Resin Systems

Uvacure	Description	Comments
1561	Hybrid epoxide / acrylate for cross reactive polymerization ; higher viscosity	Faster initial cure, increased strength , improved chemical Resistance
1562	Hybrid epoxide / acrylate for interpenetrating network polymerization	Lower viscosity, recommended for plastic and metal coatings, low odor

New Cationic Resins (Experimental)

The new experimental cationic resins developed are designated as CAT products with typical properties like improved surface hardness, stain resistance, water resistance, low odor and barrier properties. These products are listed in Table V.

Table V: Experimental Cycloaliphatic Epoxide Resins

CAT	Description	Comments
001	Modified cycloaliphatic epoxide	High cure speed, strength, surface hardness, chemical and stain resistance
002	Modified cycloaliphatic epoxide with weight per epoxide of 268, weight per hydroxyl of 312	Good water resistance, flexibility and toughness for metal varnish, coatings on wood, paper, metals, plastics, etc
003	Cycloaliphatic epoxide with weight per epoxide of 252	Low viscosity, additive to improve water resistance. Flow agent
004	Cycloaliphatic epoxide mixture with weight per epoxide of 150	Low viscosity. Recommended for use in barrier coatings on plastics
005	Cycloaliphatic/aliphatic epoxide mixture with weight per epoxide of 156	Spray applications, diluent for lower viscosity formulation

006	Cycloaliphatic/aliphatic epoxide mixture with weight per epoxide of 156	Spray applications, diluent for lower viscosity formulations. Reduces odor emitted by sulfonium salt Photoinitiators
007	Modified cycloaliphatic epoxide	Very good pigment wetting properties. Improves water resistance.

TYPICAL PROPERTIES

Table VI shows the typical physical properties of the Uvacure Cycloaliphatic Epoxide Resins, Modified Cycloaliphatic Epoxides, and Hybrid Resin Systems.

Table VI: Typical Properties

Product Category	Product	Typical Properties				
	Uvacure	Viscosity[1]	Color[2]	WPE[3]	Density[4]	Refractive Index[5]
Cycloaliphatic Epoxide Resins	1500	275	80	134	1.17	1.4965
	1501	280	100	135	1.17	1.4980
	1502	80	80	131	1.13	1.4938
Modified Cycloaliphatic Epoxides	1530	400	80	184	1.14	1.4912
	1531	500	80	227	1.13	1.4881
	1532	660	80	273	1.12	1.4855
	1533	310000	(2)	262	1.10	1.4898
	1534	2300	(1)	268	1.10	1.4862
Hybrid Resin Systems	1561	150000	(5)	451	1.18	1.5631
	1562	3800	(1)	223	1.17	1.5211

Table VII lists the tensile (stress / strain) properties of the product line[6].

Table VII: Tensile Properties

Uvacure	Tensile Strength @ Max. load, psi	Elongation @ max. load, %	Tensile Strength @ Break, psi	Elongation @ break, %	Young's Modulus psi	Toughness psi
1500	6000	7	6000	7	152000	230
1501	5600	6	5600	6	175000	240
1502	3600	8	3400	19	96000	590
1530	8720	8	8700	8	200000	460
1531	4710	42	4670	47	112000	1990
1532	2780	140	2780	140	5020	1690
1533	510	230	510	230	870	540
1534	3600	135	3600	135	48000	3420
1561	11200	8	11200	8	242000	540
1562	10500	6	10500	6	240000	420

Table VIII: Typical Properties of CAT Resins

Product Category	Product	Typical Properties			
	CAT	Viscosity[1]	Color[2]	WPE[3]	Density[4]
Cycloaliphatic Epoxide	001	10000	(4)	195	1.15
	002	7000	(1)	286	1.13
	003	50	(2)	252	1.02
	004	100	(2)	150	1.15
	005	85	20	156	1.12
	006	85	20	156	1.12
	007	6200	(8)	373	1.08

[1]cP at 25°C
[2]Pt –Co scale. Values in parenthesis are Gardner scale
[3]Weight per epoxide
[4]g / ml at 25°C
[5]n_D at 25°C
[6]tested in general accordance with ASTM D882

Applications

Uvacure cycloaliphatic epoxide resins, modified cycloaliphatic epoxides, and hybrid resin systems are useful in a variety of applications, including:

- Adhesives
- automotive sealants
- can end varnishes
- flexo and screen print inks
- glass coatings
- metal decoration basecoats
- metal deco inks
- paper coatings
- plastic substrate coatings

FORMULATING GUIDELINES

Background

The following general formulating guidelines are intended to aid the formulating chemist in developing optimum properties needed for a particular application.

General Formulating Principles

Resin selection

In general, the major component of a cationic formulation is the cycloaliphatic epoxide resin workhorse, Uvacure 1500. Uvacure 1500 provides the major film forming properties, while other components are modifiers. Such other materials may include other cycloaliphatic epoxides such as limonene monoxide or di – epoxide, and glycidyl ethers.

Addition of these materials will modify film properties and may also result in increased odor, decreased cure speed , increased viscosity , and lower cost . Addition of components like epoxidized polybutadiene can provide increased chemical resistance, flexibility, toughness, impact strength, and decreased hardness.

Addition of vinyl ethers at 10 – 15 % of the formulation, in addition to viscosity modification, may provide faster initial cure and will result in an interpenetrating network structure by virtue of two cationic cure mechanisms. See Fig.7.

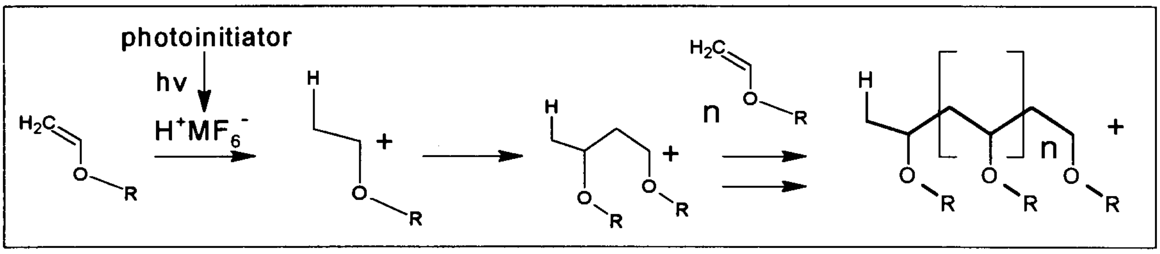

Fig.7. Cationic Polymerization of Vinyl Ether

Photoinitiator Selection

Cationic photoinitiators may consist of sulfonium, iodonium, ferrocenium, or diazonium salts. Cationic photoinitiators systems are typically used at concentrations of 1 -3 % active materials.

Examples of sulfonium salt photoinitiators are shown in Fig 8. The sulfonium salts are present as a blend of materials, and the products supplied by the different vendors differ in counter ion (PF_6^- or SbF_6^-) and solvent (Fig.9).

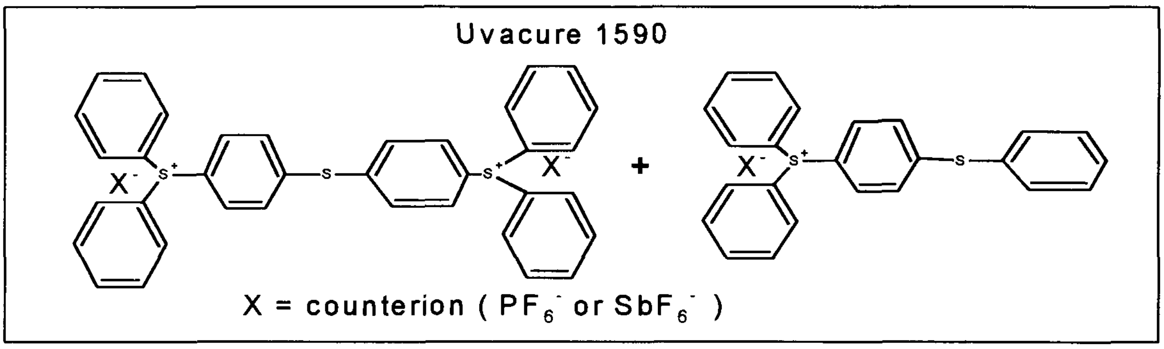

Fig.8. Sulfonium Salts

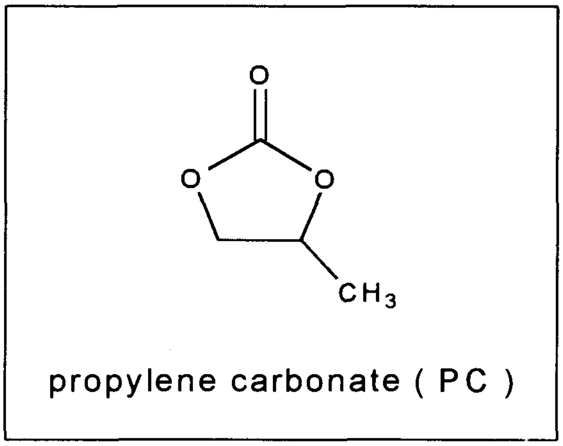

Fig.9. Solvent for Sulfonium Salts

Iodonium salts initiate cationic polymerization in a manner similar to that shown for the sulfonium salts.

Ferrocenium salts, such as Irgacure 261 shown in Fig. 10, generate a Lewis acid. Ferrocenium salts photo - bleach on exposure to UV light, which allows the curing of thicker films, however, the bleaching is insufficient to provide colorless films.

Ferrocenium salt can also be photosensitized, for example with anthracene. Also, cumene hydroperoxide can oxidize ferrocenium salt to yield a stronger Lewis acid, which can reduce cure temperature or cure time.

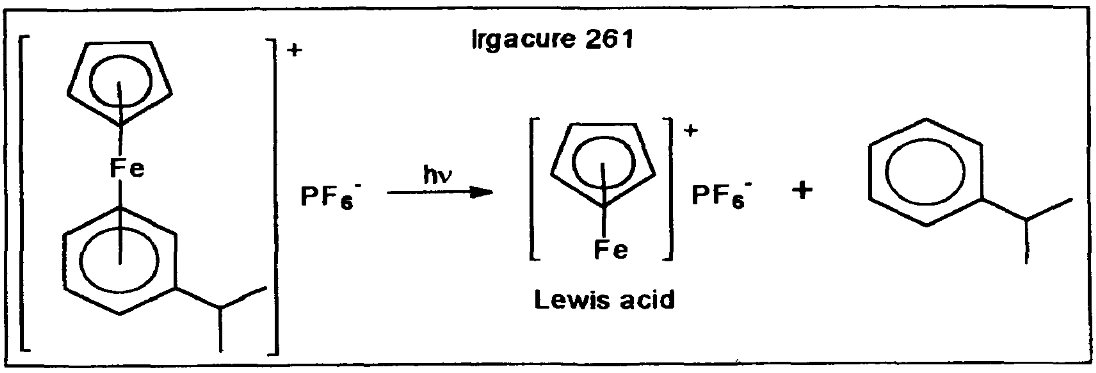

Fig.10. Ferrocenium Salt

Diazonium salts, the earlier cationic photoinitiators, afford poor pot life, and give colored coatings. They also evolve nitrogen gas on curing (see Fig.11) which cause problems in film, such as pin – holes and poor gloss.

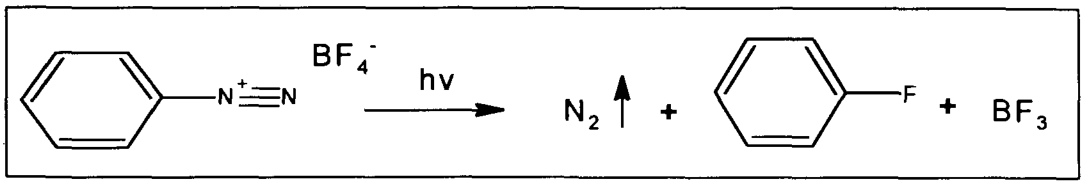

Fig.11. Diazonium Salt

Counterions, in addition to affecting the solubility of the photoinitiator system, can have other effects on the final product. Fig. 12 shows the general effect of photoinitiator counterion including Br^-, BF_4^-, PF_6^- and SbF_6^-. The trend is to increase cure speed as the counterion goes from more nucleophilic to less nucleophilic. PF_6^- seems to be the best choice for adhesion to metals and for less yellowing on heating.

Br^-	BF_4^-	PF_6^-	SbF_6^-
Slower cure	⟶		faster cure
More nucleophilic	⟶		less nucleophilic

Fig.12. Photoinitiator Counterion Effects

As with free – radical chemistry, photosensitizers can be used with cationic photoinitiators to shift wavelength of absorption when necessary. Typical sensitizers include anthracene, isopropylthioxanthone (ITX), perylene, and phenothiazine.

Modifying formulations

Epoxy Hydroxy Ratio (EHR)

When formulating with hydroxy functional materials, the epoxy Hydroxy Ratio or EHR is a useful concept. This is the number of epoxy groups per number of hydroxy groups. It has been shown that an EHR greater than 1.5 and less than 10 can be useful, and for each formulation there is an optimum. For coatings applications, an EHR of 3 to 6 is common. Generally, as EHR increases, hardness, solvent resistance, adhesion, and surface cure rate also increase. Conversely, impact resistance and through cure rate increase as EHR decreases.

Weight per Hydroxyl

Weight per hydroxyl also affects final properties. Flexibility and adhesion increase as equivalent weight increases. Hardness, solvent resistance, cure speed and crosslink density increase as equivalent weight decreases.

Hydroxy Containing Compounds

A wide variety of hydroxy functional materials can be formulated with cycloaliphatic epoxide resins: alcohols, polyester polyols, polyether polyols, castor oil, hydroxy functional vinyl and acrylic resins, cellulose esters, and phenoxy resins. These materials can be used to modify the formulation and cured film properties. Table VII summarizes these effects.

- For example, primary hydroxyls react faster in these systems than secondary hydroxyls, as would be expected. This is illustrated by the difference between the cure speed with typical caprolactones (1° hydroxyls) and polyether polyols (1° and 2° hydroxyls)

- The various reactive thickeners in Table IX are useful particularly for systems which typically are low viscosity , for substrate hold – out , or for rheology modification. The reactivity of these materials adds to the final film properties.

Table IX: Effects of Hydroxy – functional Materials on Formulation

Hydroxy–functional species	Effect on formulation
Alcohols and Glycols	Lower cost, decrease viscosity , can decrease cure speed, increase wetting and adhesion
Polyester polyols	Increase toughness, flexibility , low color materials available, caprolactones are best
Polyether polyols	Decrease cure speed, increase flexibility
Castor oil	Good pigment wetting, fast cure , good abrasion resistance , good behavior on retort
Hydroxy – functional vinyl and acrylic resins	Reactive thickeners, increase adhesion , flexibility, and water resistance
Cellulose esters	Reactive thickeners , add thixotropy, improve holdout on porous substrates , useful in wood applications
Phenoxy resins	Reactive thickeners, improve gas barrier properties, increase adhesion, improve solvent resistance.

Other Epoxy Materials

Aromatic and aliphatic glycidyl ethers and esters can also be used to modify formulations containing Uvacure Cycloaliphatic Epoxides. Also, the good pigment wetting obtained from epoxidized castor oil results in especially good flow and high gloss. Additionally, good behavior on retort, which is important for the can coating industry, can be achieved with epoxidized castor oil.

Use of Additives

Additives are used in cationic formulations for the same general reasons as other formulated systems. Surfactants, pigments and fillers, slip additives, waxes, and anti-foam agents are examples of some of these additives. It is imperative, however, to avoid basic additives, as basicity will inhibit cationic cure. Acidic materials can also destabilize the formulation.

Inhibition by High Relative Humidity (RH)

Because of the importance of the acid species to the cationic UV mechanism, components of the formulation or of the substrate surface which may neutralize the acid species may significantly inhibit the cure. It is important to be aware of these possible effects, to avoid basic species, or to compensate by adding excess photoinitiator or by using higher UV light energy or by operating at a lower cure speed.

Use of Thermal Energy

It is common to use a post – cure heat 'bump' to accelerate development of final properties of cationic cured systems. Mild heating of the coated substrate prior to UV cure may mitigate the effect of high relative humidity.

STARTING POINT FORMULATIONS

The following starting point formulations demonstrate the utility of Uvacure Epoxide resins for a variety of cationic cure end – uses. These formulations have not been optimized but are intended as an aid to the formulator of coatings, inks, and adhesives.

Metal Coatings

Clear Topcoats for Untreated Aluminum

Table X summarizes three starting point formulations as clear topcoats for untreated aluminum. Coatings were applied with a No. 5 wire wound rod. These formulations were cured at 75 mJ/ cm^2 (one 120 Watt / cm Fusion 'H' lamp at 60 m / min.), at 25 ° C, in relative humidity < 30 %.

Table X: Clear Topcoats for Untreated Aluminum

Constituent	Formulation A	Formulation B	Formulation C
Uvacure 1500	24.6	56.7	40.0
Uvacure 1530	69.9	37.8	-
Uvacure 1561	-	-	34.0
TMPTA – N (UCB)	-	-	20.0
Uvacure 1590	5.0	5.0	2.5
Irgacure 500 (Ciba)	0	-	3.0
Silwet L – 7602 (Witco)	0.5	0.5	0.5
TOTAL	100.0	100.0	100.0
EHR	3.0	6.2	-
Viscosity, cP @ 25 ° C	450	350	1500
Performance			
Immediately after UV – Cure			
Adhesion , %	100	100	100
MEK double rubs	< 10	< 10	20
Pencil Hardness	3H	2H	3H
Conical bend, inches	0	>4	3
24 hours after exposure			
Adhesion, %	100	100	100
MEK double rubs	>60	>100	>200
Pencil Hardness	3H	2H	3H
Conical bend, inches	0	0	> 4

Impact Resistant Coating for Stainless Steel

Table XI shows a starting point formulation for a clear impact resistant coating for stainless steel. The coating was applied at 10μ and cured at 250 mJ/cm^2 (one 80 watt/ cm medium pressure mercury vapor lamp at 10 m/ min)

Table XI: Impact Resistant Coating for Stainless Steel

Constituent		Weight Percent
Uvacure 1500		61.3
Uvacure 1533		20.0
CAT 003		6.4
1,6 – hexanediol diglycidyl ether		6.4
Ethylene glycol		3.2
Uvacure 1590		2.4
Silwet L – 7602 (Witco)		0.4
	TOTAL	100.0
Viscosity , cP @ 25 ° C		344
Performance		
Adhesion , %		100
Direct Impact, inch – lb.		52
Reverse impact, inch – lb.		> 100

Improving Resistance of Metal Coatings

Table XII illustrates the differences in chemical and impact resistance which can be obtained by using the Modified cylcoaliphatic epoxides (Uvacure 1530, 1531, 1532). These coatings were applied with a No.5 wire wound rod to iron phosphated steel and cured at 235 mJ/cm^2 (one 120 watt/cm Fusion 'H' lamp at 24 m / min.), at 25 °C at approximately 60 % relative humidity.

Table XII: Improving Resistance of Metal Coatings

Constituent	Formulation A	Formulation B	Formulation C
Uvacure 1500	56.7	52.9	47.3
Uvacure 1530	37.8	-	-
Uvacure 1531	-	41.6	-
Uvacure 1532	-	-	47.2
Uvacure 1590	5.0	5.0	5.0
Silwet L – 7602	0.5	0.5	0.5
TOTAL	100.0	100.0	100.0
EHR	6.2	6.2	6.2
Viscosity, cP@ 25°C	316	352	424

Performance			
Immediately after UV –			
Cure	< 2	6	>160
Reverse impact, inch-lb.	12	10	10
MEK double rubs	3H	2H	2H
Pencil Hardness	100	100	95
Adhesion, %			
10 days after exposure	< 2	< 2	120
Reverse impact, inch LB	>200	81	19
MEK double rubs	8H	8H	5H
Pencil hardness	100	100	100
Adhesion, %			

OVERPRINT VARNISH

Low viscosity, Low odor OPV

Table XIII lists a starting point formulation for a low viscosity overprint varnish with low odor. This coating was cured at < 50 mJ/cm^2 (one medium pressure mercury vapor lamp, 80 watt/cm, > 100m / min.)

Table XIII: Low Viscosity, Low Odor OPV

Constituent	**Weight Percent**
Uvacure 1500	34.0
Uvacure 1562	20.0
DEN 431 (DOW)	15.0
Ethanol	27.3
Uvacure 1590	3.0
Benzophenone	0.3
BYK 354 (BYK CHEMIE)	0.2
BYK 088 (BYK CHEMIE)	0.2
	100.0
TOTAL	
Viscosity , cP@ 20°C	~ 35
Performance	
MEK double rubs, immediate	2
MEK double rubs, 24 hours	50

ADHESIVE

Laminating adhesive

Table XIV gives a starting point formulation for a laminating adhesive for substrates, which are not transparent to UV light. Lamination can be done immediately after UV exposure. Cure dosage was 35 – 75 mJ/cm^2 (one 80-watt/cm lamp at 50 –100 m/min.). Full cure properties were developed after 60 minutes. The formulation exhibited good adhesion to polyethylene, polyester, BOPP, polycarbonate, aluminum, and steel.

Table XIV: Laminating adhesive for Plastic and Metal

Constituent	Weight Percent
Uvacure 1534	87.3
Tripropylene glycol (DOW)	9.7
Uvacure 1590	3.0
TOTAL	100.0
Viscosity, cP @ 25° C	~ 1800

PLASTIC COATINGS

Clear Coating for Polysulfone Plastic

Table XV gives a starting point formulation for a plastic clear coat, originally developed for use on polysulfone plastic cook tops. This material was cured with an approximate dose of 1400 mJ/cm^2 (8 m /min., two 120 watt/ cm. Fusion 'H' lamps). The coating was drawn down with a No. 3 wire wound rod. The cured film was post – baked at 80°C for 15 minutes.

Table XV: Clear Plastic Topcoat

Constituent	Weight Percent
Uvacure 1500	77.5
Diethylene glycol (Shell)	18.0
Silwet L – 7602	0.5
Uvacure 1590	4.0
TOTAL	100.0
Performance	
Adhesion , %	95
MEK double rubs	50
Water resistance, 30 min. in boiling water	very slight blush

Black Pigmented Coating for Polyester Coated Aluminum

Table XVI describes a starting point formulation for polyester-coated aluminum ceiling panels. This coating was drawn down with a No. 5 wire – wound rod, and cured with an approximate dose of 1400mJ/cm^2 (8 m / min. , two 120 watt/cm Fusion 'H' lamps). The cured film was post – baked at 80 °C for 15 minutes.

Table XVI: Black pigmented Coating for Polyester coated Aluminum

Constituent	**Weight Percent**
Uvacure 1500	39.0
Uvacure 1532	29.5
Placcel 205 (Daicel Industries)	10.0
Uvacure 1590	5.0
ITX	1.0
Silwet L – 7602	0.5
9B1 black pigment dispersion (Penn Color)	15.0
TOTAL	100.0
EHR	4.4
Performance	
Adhesion ,%	100
MEK double rubs	35

ELECTRONICS

Printed Circuit board Conformal Coating

Table XVII summarizes a starting point formulation for a conformal coating on printed circuit boards. This film was applied with a No. 3 wire – wound rod, cured with an approximate dose of 1400mJ/cm^2 (8 m/ min. , two 120 watt/cm Fusion 'H' lamps) and post – baked at 80 ° C for 15 minutes.

Table XVII: Printed Circuit Board Conformal Coating

Constituent	**Weight Percent**
Uvacure 1500	46.5
Uvacure 1532	49.0
Silwet L – 7602	0.5
Uvacure 1590	4.0
TOTAL	100.0
EHR	5.9
Performance	
Adhesion , %	100

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