ACHIEVING ADHESION OF UV AND EB CURED MATERIALS TO PLASTICS

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Note to Users

This guide is intended to provide general guidelines concerning achieving adhesion of radiation cured coatings to plastic substrates. The guidance is based on general approaches which are used to achieve adhesion. Since every coating and every substrate is unique, it must be understood that the number one approach is always “try, test and do”. Recommendations and suggestions found herein are meant only to guide the process development to achieve success (conforming to requirements) as quickly as possible.

Introduction

It is the purpose of this brief pamphlet to introduce the reader to the various and sundry concepts for achieving adhesion of UV and EB cure coatings to plastic substrates. Our target reader is one who has limited knowledge of radiation cure and is interested in achieving a final painted product with a desired set of properties. The reader could be a coatings formulator or applicator who wishes to realize the many advantages of using UV or EB and wants to know more about assuring good adhesion.

Because of the rapid cure, low solvent and low energy cure characteristic of UV and EB coatings, they have often developed a reputation for “easy release characteristics” (poor adhesion). But have no fear. We have ways for dealing with this.

The End Game – Where Do You Want to Go and How Do You Get There?

When designing a painting process one must choose the appropriate coating and the appropriate substrate. Considerations for these choices begin with the intended end use. Is this an exterior or interior use? Exposure conditions, weathering and thermal cycling can affect adhesion. Will the coated material be exposed to physical attack (abrasion, scratching, gouging, impact, etc.). Deformation of the coated substrate can lead to adhesion loss. How about chemical attack (water, solvent, oils, harsh chemicals, etc.)? These can loosen the bond between the coating and the plastic substrate. What is the expected life of the object? Coating on a one-time-use disposable object doesn't have to last long. But what if it is supposed to sit outdoors for years? What if it must take a physical beating (one time or repeated deformation)?

You also need to decide what you want out of the coating. Is the coating to be clear or solid color. What film thickness is required? For UV, thick solid color films offer the greatest challenge for adhesion. Light has difficulty getting through pigmented films and thick films. For EB, solid colors pose much less of a problem, but film thickness still counts, especially for lower kilovolt (kV) beams.

Once you've defined the end use requirements of the object or material to be painted, you then decide on the production process. Often the production line process used to form or handle the plastic will limit the type of plastic. Cost, of course, also figures into choice of substrate material. Another part of the production process is the painting process. For UV or EB cure, the painting process steps possibly include some sort of pretreatment (cleaning/activation), followed by paint application, possibly time/temperature delay for flowout/solvent evaporation followed by exposure to UV or EB. In some cases there may also be a thermal treatment after UV/EB.

You Want to Coat What Kind of Plastic?

The type of plastic you are dealing with has a great effect on the affinity between substrate and coating. There are many different types of plastics available. Some are well known to be more "paintable" than others. Clearly, if you can specify a paintable grade of plastic you are better off. But this is no guarantee since different paints have different adhesion characteristics.

One way a coating gets adhesion to a plastic is by slightly dissolving the surface of the plastic. Different plastics have different resistance to dissolution. Plastics like olefinics and PET are solvent resistant, whereas others such as polycarbonate and PVC are more subject to attack.

Next, there may be the opportunity to pretreat the plastic (corona, flame, liquid, etc.). The different pretreatments work differently on different plastics. So knowing that a certain pretreatment is available can influence the choice of plastic to be coated.

Another consideration is the type and location of release agents associated with the chosen plastic. Frequently, a release agent is needed to keep the melted plastic from sticking to the forming equipment. To do its job, the release agent must be on the surface of the plastic. If it is still there when the plastic is ready to be coated, there can be big problems such as cratering or loss of adhesion. Fortunately, some release agents are friendlier to paints than others, and also there are paint additives that can overcome the "release" in the release agent. Clearly, some types of cleaning and other pretreatments can also eliminate the negative effects of release agents. Finally, it should be noted also that release agents imbedded in the plastic can sometimes come to the coating-substrate interface later on in life and hurt adhesion.

You Want to Apply What Kind of Coating?

The type of coating chosen is usually closely related to the end use requirements and to the chosen process. The predominant coating materials used in UV and EB curing are acrylates. There is a wide range and ever increasing number of acrylate monomers and oligomers available from numerous suppliers. They have different adhesion characteristics. It is often helpful to obtain supplier recommendations as to which would be most suitable for your intended use.

One consideration on choice of a coating material is its shrinkage characteristics. Generally, the more highly functional (higher crosslink density; greater percent functionality) the components of the coating are, the more the shrinkage. More shrinkage usually results in greater internal stress at the bond between the coating and the substrate. The laws of thermodynamics suggest that the stresses will want to relieve themselves: frequently by loss of bonding - i.e. no more adhesion! Why choose highly functional components? They usually give faster cure and harder, more stain resistant coatings. Keep this "trade-off" in mind when addressing adhesion problems.

Speaking of hardness, another consideration on coating characteristics is glass transition temperature (Tg). Tg is somewhat akin to "melting", but not nearly as distinct a transition. Similar to melting, when the coating and/or plastic substrate is BELOW the Tg they tend to be harder and more stain resistant; above the Tg: softer, more pliable. Frequently, being above the Tg will enhance adhesion. So coatings and subtrates with low Tg's are more likely to stick.

How Do You Make Them Get Along With Each Other?

Facts of life: coatings formulators hate to change their formulas and coatings applicators hate to change their processes. But when there's no adhesion, compromise is necessary! Clearly if choice of plastic is possible, one tests the choices available to find the best candidate. Frequently complete freedom of choice of plastic is not possible. If there are adhesion concerns, one can modify the coating, the plastic, or both.

Modifying the coating:

1. Consultation with raw material suppliers is always recommended. They frequently have seen situations similar to yours and can offer useful starting formulas. Also, many suppliers offer to do development work for their customers.
2. See above discussions on Tg, functionality and shrinkage. It should be noted here that cationic epoxy systems frequently have lower shrinkage characteristics than acrylates since their polymerization involves a ring opening reaction.
3. Low Tg additives or reactive components can help adhesion. However, loss of hardness, and possibly other properties can be expected.
4. Another consideration is polarity/functionality. Generally more polar coatings stick better, especially to more polar substrates. One very polar group is acid functionality, which is often used to afford adhesion. Stronger acids usually give more adhesion. However, acids can interact with other components such as amines. Less polar groups (hydroxyl, amine, aldehyde, ketone, ester) can help.
5. Chlorinated polyolefins (CPO's) are frequently used to enhance adhesion. Generally they are used by themselves as primers because they are not very compatible with UV/EB coatings. Investigate using the most compatible forms of these. Proper choice of monomers (or solvents, if allowed) can help incorporate CPO's.
6. Surface tension of the coating and the substrate must always be considered. You want the surface tension of the substrate to be higher than that of the coating. Often adhesion problems are solved merely by lowering the surface tension of the coating with an additive. Additives containing silicon are very effective at lowering surface tension but can cause other problems. (Consult your friendly additive suppliers.)
7. As mentioned in a previous section, adhesion can be enhanced by components in the coating by slightly dissolving the surface of the plastic substrate. Again, judicious choice of diluent (or, if allowed, solvent) can help. Keep in mind, however, that too much attack can lead to problems such as softness, blushing, etc.
8. Another method is including a species that reacts with functionalities on the substrate surface. For instance, including silane or isocyanate moiety in the coating can lead to more secure bonding to the plastic surface ("dual cure" approach). However, this can necessitate going to a two component (2K) system.

Modifying the substrate:

1. First, consider cleaning the plastic. Poor adhesion is often due to contaminants on the plastic surface. Water based cleaning processes can be multi-staged, and the last stage can contain a small amount of adhesion promoter. Drying the cleaned substrate with heat can enhance adhesion because the warm substrate will be more amenable to etching by the coating's solvency and substrate temperature may bring it above Tg. Solvent base cleaners and cleaning systems such as vapor degreasing are another option.
2. Abrading the substrate gives rise to more surface area available for bonding (more total substrate surface energy per unit area of applied coating). It also can remove contaminants that are hurting adhesion. Besides simple sandpaper or steel wool, many other forms of abrasive materials are available. One may want to consider some form of media blasting (sand blasting). Media can be propelled by air or water ("wet blasting").
3. There are numerous treatments which chemically modify the plastic surface: corona treating, flame treating, and plasma treating. Combinations such as atmospheric plasma treating are also under development. These methods create new moieties on the plastic surface which are more polar (increasing substrate surface energy) and often reactive.
4. Primers are frequently used to enhance adhesion. As mentioned above, a favorite is based on CPO, but many others are available.
5. It should be noted that some substrate modifications may have a dual mode such as softening AND roughening the surface. That is, it has been pointed out, for instance, that some solvents that swell the surface actually lead to adhesion by causing actual topographical changes that, in turn, provide adhesion.

Do They Really Get Along With Each Other?

One should be diligent in characterizing how good the adhesion really is. There are many adhesion tests available and one should use as many as possible to make sure the adhesion meets expectations. The traditional tape test is good for a start. There are many types of tape with different adhesive characteristics: use some real sticky tapes. Cross hatch spacing can be varied along with depth and angle of cut. Try taping the crosshatched area several times and taping diagonal in addition to straight on.

The tape adhesion test is ultimately only as good as the strength of the tape adhesive. There are tests such as the PATTI test which use the bond strength of two component epoxy adhesive.

Other tests which can detect less than acceptable adhesion are scrape adhesion tests such as pencil hardness, "nickel scratch", Hoffman scratch, Tabor scratch, Balanced Beam, etc.

One may want to test adhesion by challenging the adhesive bond with moisture (humidity + tape test immediately after drying); with flexing (impact + tape test or worse yet crosshatch + impact + tape test); hot / cold cycling + tape test; etc.

The main idea is to work at challenging the bond between the coating and the plastic to know how strong and robust the adhesion really is. Keep in mind the end use requirements so that the test fits the application.

How Long Will It Last?

Finally, it is wise to consider testing adhesion AFTER the coated substrate has been subjected to the kind of use intended for the coated part[8]. For instance, if the part is intended for exterior use subject to weathering, one should test adhesion after the coated substrate has been exposed to accelerated weathering such as QUV, Weather-O-Meter, Florida, Arizona exposure.

For interior applications, one must consider expected lifetime. For disposable packaging or publications, the lifetime may be very short. For other interior applications, lifetime may be longer, perhaps 3-5 years for instance. One may want to do accelerated aging in a hot box (typically 50ºC) followed by an adhesion test.

Again, the main idea is to work at challenging the bond between the coating and the plastic to demonstrate that the adhesion will always survive the actual expected customer use.

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The RadTech Plastics Focus Group has prepared this Guide as part of our UV/EB technology educational efforts. For further information contact RadTech at www.radtech.org or uveb@radtech.org.
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UV/EB Plastic Coatings Adhesion Guide

Type of Plastic	Chemistry	Estimated Ease of UV Coatability	Corona/Flame/Plasma Pretreatment Suggestions - ref #4 Suggested Type	For Solvent Base Paints Dynes	For Water Base Paints Dynes	For UV Cure Paints Dynes	Possible Approaches	Reference
ABS	Acrylonitrile-Butadiene-Styrene Terpolymer	1	C,F	42-46	44-48	46-56	a	1
ASA	Acrylonitrile-Styrene-Acrylate Terpolymer	1	C, P	38-48	40-44	42-54	a	5
EPDM	Ethylene-Propylene-Diene-Monomer	3	C, F	38-45	40-48	44-60		
FP's	Fluorinated ethylene-propylene	3	P	38-45	40-48	44-60		
PA	Polyamide	1	C, P	46-55	48-60	50-60	npt	2
PBT	Polybutylene Terephthalate	2	F, P	38-45	40-48	44-60	a	5
PC	Polycarbonate	2	C	46-55	48-60	50-60	a, sa	1, 3
PE(HDHMW)	Hi-density polyethylene Hi-MW	2	F, P	38-45	40-48	44-60	a	5
PE(HDUHMW)	Hi-density polyethylene UltraHi-MW	2	F, P	38-45	40-48	44-60	a, sa	5
PE(L,M,H)	Polyethylene	2	C,F	38-45	40-48	44-60	c, npt, sa	2, 3
PET	Polyethylene Terephthalate	2	C	42-48	46-60	48-62	a, npt, sa	2, 3
PMMA	Polymethyl methacrylate	2	C	38-48	40-44	42-54	sa	5
POM	Polyoxymethylene		P	38-45	40-48	44-60		
PP	Polypropylene	3	F,P	38-45	40-48	44-60	npt, sa	2, 3
PPE	Phenylene Ether Co-polymer	2	P	38-45	40-48	44-60	sa	5
PS	Polystyrene	2	F, P	38-45	40-48	44-60	a	1
PUR	Polyurethane	3	P	42-46	44-48	46-56	a	5
PVC	Polyvinyl Chloride	2	C	40-45	42-48	44-60	a, npt	1, 2
TPU	Thermoplastic Urethane	3	C,P	42-46	44-48	46-56		
PPO/PPE	Phenylene Oxide / Phenylene Ether	2						
TPO	Thermoplastic Polyolefin	3					cpo, sa	3
BMC	Bulk-Molding Compound	2					a	5
PETG	Polyethylene Terephthalate Glycol	2					sa	5
SAN	Styrene Acrylonitrile	2					sa	5
		1=Relatively easy	C=Corona					
		2=Moderate	F=Flame					
		3=Difficult	P=Plasma					

References	1	Adhesion of Radiation Cured Coatings to Plastics	Sartomer	Application Bulletin	a=adhesion additive to coating
	2	New Priming Technology Adhesion Performance of UV	Villeneuve	JCT May 2004	sa=special adhesion additive to coating
	3	How to Get Enhanced Adhesion to Plastic Substrates	Carroy	E5 2006	cfp=corona, flame, or plasma pretreatment
	4	Surface Treatment Chart	Enercon Industries		c=corona pretreatment
	5	Eileeen Weber	RedSpot Paint & Varnish		cpo=cpo primer
	6		RedSpot Paint	www.redspot.com/products/prod_uvapp_uvcured.asp	npt=new priming technology