Tailor-Made UV-Curable Powder Clear Coatings for Metal Applications

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Summary: UV-curable powder coatings combine most of the benefits of conventional powder coatings together with the advantages of radiation-curable liquid coatings. This new coating process is not only environmentally friendly. It can also be used to coat substrates like wood, plastic, glass or metal at low temperatures within a short curing time. Several coatings based on binders like urethane vinylethers/unsaturated polyesters or methacrylates are developed for metals, wood or pvc flooring. This paper describes urethane acrylates as a new resin system for UV-curable powder clear coatings. The binders can be amorphous or (semi)crystalline. By combining both types it is possible to get tailor-made binders which exhibit an unique coating performance of excellent adhesion, good flexibility and high hardness on metal substrates. The appearance of the clear coatings can be varied from high to low translucent. In addition, the coatings show a good weatherability.

Introduction

Conventional thermosetting powder coatings are well-established since more than 30 years for many interior and exterior applications. They are accepted because of their outstanding balance between energy savings, no solvent emission and high film performance. Liquid UV coatings run with high line speeds because of the fast crosslinking reaction of the binder. However, they contain reactive diluents which are irritating and smell badly. Furthermore, these coatings have adhesion problems due to their high shrinkage during the crosslinking.

It seems reasonable to assume that a combination of both technologies, generating UV-curable powder coatings, should bring benefits. In deed, UV powders don't need irritating monomers, have low shrinkage during curing and can coat temperature sensitive substrates like thermoplastics, wood, paper and pre-assembled metals or alloys. In contrast to thermosetting powder coatings the melting and curing processes are separated from each other (see figure 1). So, very smooth films can be achieved. The performance of such films is good to excellent.

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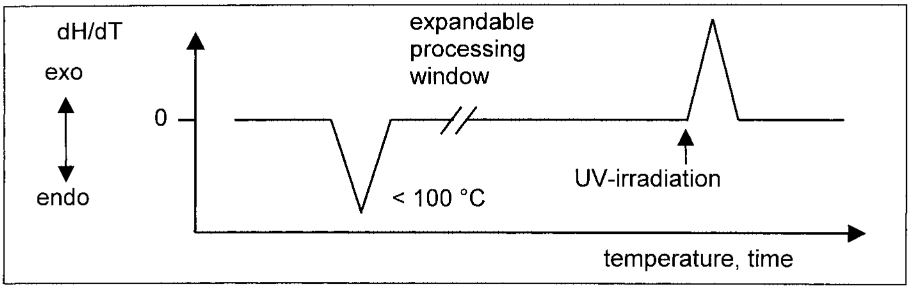

Figure 1. Melting and curing process of UV-curable powder coatings (DSC)

Therefore, UV-curable powder coatings will play an important role in the very near future of the coatings industry.

UV powder coatings are commercially available for several years. The binders used for these coatings differ chemically from the system introduced here.

Solid epoxy resins based on bisphenol-A are cured cationically. A photoinitiator generates, upon irradiation with UV light, a strong acid resulting in cationic polymerization of the epoxy groups [1]. This kind of polymerization exhibit low shrinkage, no inhibition by oxygen and can be post-cured thermally. Alcohols can added as chain extenders to influence mechanical properties and cure characteristics of the coatings. Lower polymerization speed and inhibition of the curing reaction by water are disadvantages compared to radically cured films.

Unsaturated polyesters combined with urethane acrylics or urethane vinylethers as hardeners have been designed recently [2,3]. These UV-curable coatings are cured by free radical polymerization.

Acrylated and/or methacrylated polyesters as special amorphous or (semi)crystalline binders are developed for the coating of metal, wood or pvc substrates [4]. The films exhibit excellent surface properties like chemical and scratch resistance. By using binder mixtures of amorphous and (semi)crystalline resins the flexibility of the cured films can be increased. However, the hardness of the coating doesn't remain on a high level.

New binders are needed which gives flexible and hard films. Urethane acrylates are a new class of binders for UV-curable powder coatings. They are cured by a free radical polymerization process.

New resins for UV-curable powder coatings

The performance of one amorphous and three (semi)crystalline urethane acrylates (UA) was studied (see table 1).

Table 1. Physical properties of urethane acrylate binders

Binder	Melting Point (°C)	Tg (°C)	Viscosity (Pa·s, 120°C)
Amorphous UA 1	80-82	49	270
Crystalline UA 1	77	/	1.3
Crystalline UA 2	68	/	1.8
Crystalline UA 3	110	/	1.0

Tg and viscosity can be adjusted by mixing the amorphous resin with a (semi)crystalline resin. The higher the amount of (semi)crystalline urethane acrylate in the mixture the lower the values of Tg and melting viscosity.

These binders are formulated to powder clear coatings (see table 2).

Table 2. Standard Formulation for UV powder clear coatings

Binder 1	Binder 2	Photoinitiator	Degassing agent	Flow agent
827 g Amorph. UA	146 g Cryst. UA	10 g AHK[1]	10 g	7 g
778 g Amorph. UA	195 g Cryst. UA	10 g AHK*	10 g	7 g

[1]AHK: α-hydroxyketone

The ratio of amorphous to (semi)crystalline resin is 85 : 15 or 80 :20, respectively.

Curing conditions

The clear coatings have been applied on steel substrates with a layer thickness of 80 ± 20 μm. By melting the powder coatings with infra red light within 100 s the temperature of the films raised to 125 °C maximum (see figure 2). After a cooling phase of about 60 s down to 95 °C the films have been cured with UV-light. We used a mercury vapour lamp of 120 W/cm. The UV-dose of 3000 mJ/cm^2, measured with the Power Puck, consists of the sum of UV-A to UV-V radiation regions.

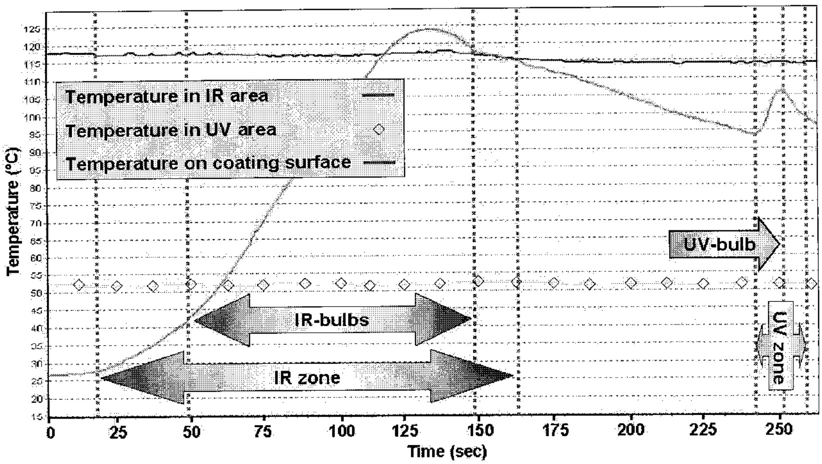

Figure 2.Typical heating and curing cycle of UV powder coatings on metals

Coating properties

UV powder coatings based on amorphous urethane acrylate resins have a high hardness (see table 3). But flexibility and smoothness of the coatings are poor. (Semi)crystalline urethane acrylate resins give very flexible but soft films.

Table 3. Film properties of UV powder clear coatings

Physical test methods	Amorphous UA	Crystalline UA
Pendulum hardness (s)	224	87
Cupping (mm)	2.0	> 10.0
Impact (d/i) (inch·lb)	40 / < 10	> 80 / > 80
Smoothness (1-10)	6	/

Mixtures of amorphous and (semi)crystalline were tested to overcome the insufficient coating performance. The mechanical properties could be adjusted depending on the structure and amount of the (semi)crystalline resin (see table 4). The smoothness got perfect. Although a soft (semi)crystalline resin was used the hardness values stayed on a very good level.

Looking deeper at the clear coatings based on mixtures of amorphous and (semi)crystalline urethane acrylate resins a different light transmittance behaviour was seen (see figure 3). Using the (semi)crystalline resin 1 clear coatings with a high transparency were obtained. The (semi)crystalline resin 2 decreased the transmission values of the clear coating. Clears with the (semi)crystalline urethane acrylate resin 3 absorped the visible light nearly completely. So, by using the right (semi)crystalline resin we are able to produce clear coatings with a high to very low transparency.

Table 4. Coating performance of UV powder clear coatings based on resin mixtures

Binder mixture	Pendulum hardness (s)	Cupping (mm)	Impact (d/i) (inch·lb)	Smoothness (1-10)
85 % amorph. UA/ 15% cryst. UA 1	193	> 10.0	40 / < 10	9
80 % amorph. UA/ 20% cryst. UA 1	183	> 10.0	50 / 20	9 – 10
85 % amorph. UA/ 15% cryst. UA 2	203	> 10.0	70 / 40	9
80 % amorph. UA/ 20% cryst. UA 2	192	> 10.0	> 80 / > 80	9 – 10
85 % amorph. UA/ 15% cryst. UA 3	214	> 10.0	> 80 / 70	8
80 % amorph. UA/ 20% cryst. UA 3	204	> 10.0	> 80 / > 80	8

The translucency of the clear coatings was influenced by enhancing the molecular weight of the (semi)crystalline urethane acrylate resins (see figure 4). The light transmittance of the semi-transparent clear coatings based on the (semi)crystalline resin 3 was improved significantly. The UV powder clear coating with the high transparency got higher transmission values in the UV-V region. Even this little improvement striked one immediately.

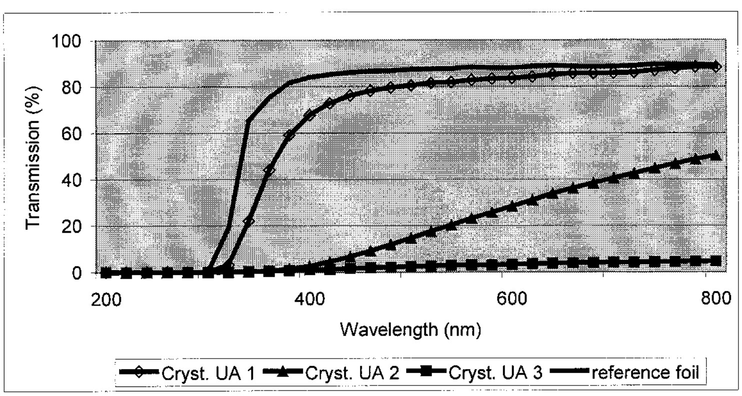

Figure 3. Transparency of UV powder clear coatings

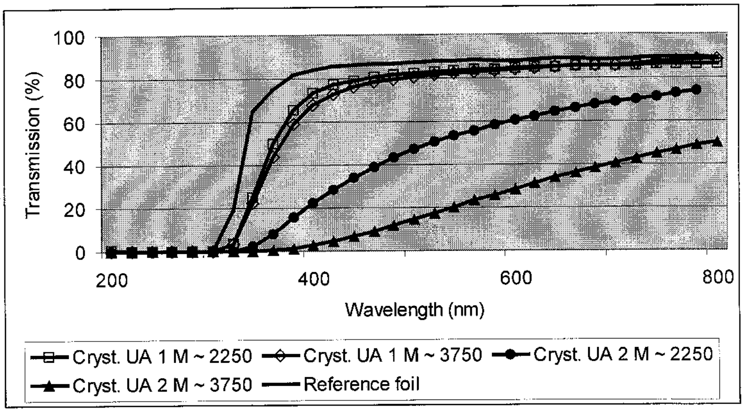

Figure 4. Increasing the transparency in UV powder clear coatings

The UV-curable powder coatings based on urethane acrylate resins showed a good weathering performance. The gloss retention in the weather-O-meter (WOM) was better than for urethane vinylether/unsaturated polyester UV powder coatings (see figure 5).

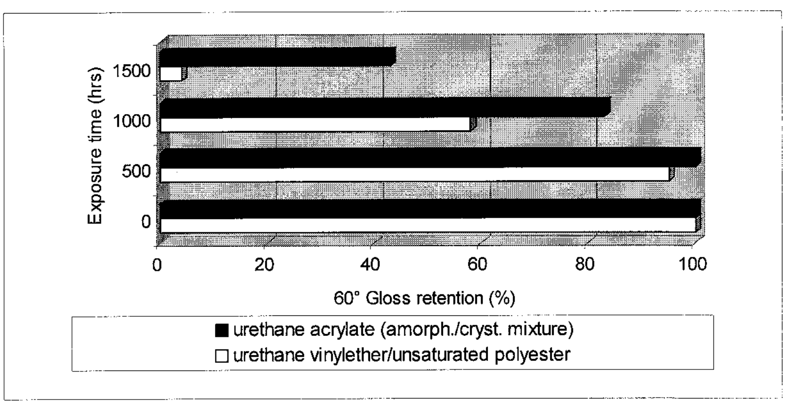

Figure 5. WOM weatherability of UV powder clear coatings

The QUV A resistance was excellent (see figure 6). There was nearly no drop in the gloss after 2800 h and an improvement in the yellowing behaviour comparing to the urethane vinylether/unsaturated polyester system.

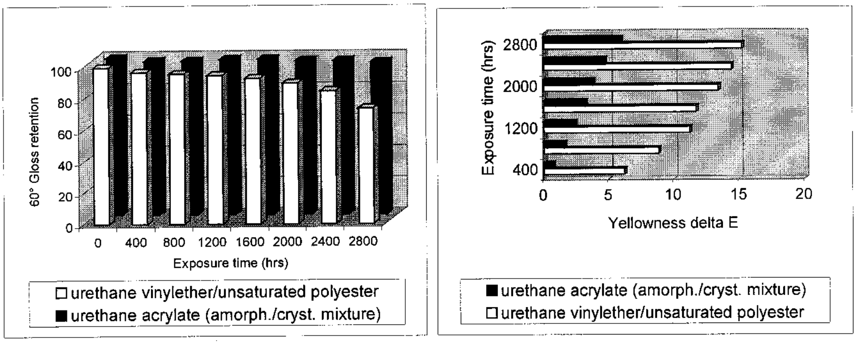

Figure 6. QUV A resistance of UV powder clear coatings

Conclusions

Urethane acrylate resins are suitable binders for UV-curable powder clear coatings. Perfect mechanical properties on metal substrates can be achieved by mixing amorphous and (semi)crystalline resins. The clear coatings with a good outdoor stability can be adjusted from high to low transparent.

The building-block principle enables customers to make tailor-made UV-curable powder coatings for their applications.

Acknowledgement

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