Enhanced Wear Protection of UV-Cured Clear Coats using Sub-Micron Aluminum Oxide Additives

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Outline

- Nanotechnology/UV-cured coatings
- Properties of sub-micron alumina particles
- Alumina dispersion development
- Scratch and abrasion resistance
- Optimization
- Summary
Waterborne UV-Curable Coatings

- High performance, high value coatings
- Can be applied to many different substrates and are used in many different markets
  - Wood: Furniture, cabinets, flooring
  - Plastic: Electronics, consumer goods
  - Paper: Graphic arts, foil, packaging
  - Metal: Automotive, can coatings
- The waterborne UV-curable coatings market has a high growth rate, largely due to:
  - Low VOCs
  - High performance compared to traditional waterborne formulations
Enhanced Wear Resistance

- In many applications, waterborne UV-curable coatings are used to protect substrates from wear-related damage.
- Additives are often used in the formulations to improve the level of surface protection: e.g. silicas, waxes, silicones.
- Each of these additives are limited in their effectiveness and may lead to other undesirable side effects.
- An ideal wear resistant additive would offer protection at low loading levels, have little to no effect on transparency, and not negatively affect other properties of the coating.
**Approach:**

Employ nanotechnology to improve the wear resistance:

- Utilize the high hardness of aluminum oxide
- Take advantage of nano and sub-micron size particles to minimize light scattering (maintain clarity) of the coating
- Engineer the particle surface treatment to ensure compatibility and performance with the coating formulation
- Optimize the particle size and loading level to achieve maximum performance
Alumina Particles - Properties

Plasma Arc Alumina:
- Non-aggregated discrete particles
- 8-9 Mohs hardness
- Dispersible at high concentration in water, solvents, and acrylate monomers
- Non-migratory in coatings
- Effective for scratch/abrasion resistance at low loadings
- Minimal impact on coating clarity
- No appreciable impact on coating viscosity, adhesion, flexibility, coefficient of friction, etc.
Formulation Compatibility

The concentrated alumina dispersions can be added directly to the coating formulation without the need for grinding, milling, or high shear dispersing.

<table>
<thead>
<tr>
<th>Particle Size, nm</th>
<th>Alumina, wt% in TPGDA</th>
<th>Alumina, wt% in H₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>40</td>
<td>30</td>
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<tr>
<td>150</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>250</td>
<td>55</td>
<td>55</td>
</tr>
<tr>
<td>800</td>
<td>55</td>
<td>55</td>
</tr>
</tbody>
</table>

100% Solids UV-Cure Applications

Waterborne UV-Cure Applications
Concentrated alumina dispersions with long-term stability

- The surface treatment must be specifically designed for the dispersion solvent to avoid particle agglomeration
- The particle surface treatment must also be compatible with all the components of the coating formulation
Design for Waterborne UV-Curable Formulations

Waterborne UV-curable formulation

- H₂O

Acrylate prepolymer

hv

Cured coating

Alumina Compatibility Design

Particle surface treatment must be compatible with the bulk aqueous phase

Particle surface treatment must be compatible with acrylate phase once water evaporates

Particles must not disrupt the cross-linking and be well dispersed in the polymer
Nanoparticle Dispersion in UV-Curable

SEM cross section of waterborne UV-cured wood topcoat

1 wt% 40 nm alumina particles
Wear Resistance in Waterborne UV-Curable

• Investigate the impact of pre-dispersed alumina additives on:
  - Coating clarity
  - Scratch resistance
  - Abrasion resistance

• Coating System
  - Waterborne low-gloss wood topcoat, 40% solids
  - Aqueous alumina dispersions post-added to the full coating formulation with stirring
  - 3 mil wft, cured at 1.8 J/cm²

• Variables
  - Particle size: 40, 150, 800 nm
  - Particle loading level: 1, 2, 5 wt%
Waterborne Low Gloss Wood Topcoat

- Reciprocating Linear Scratch Tester
  - Drawdowns on black gloss cards
  - #1 steel wool, 8 g/cm² pressure, 100 double rubs
  - Visual rating of coatings

- Taber Abrader
  - Drawdowns on clear PET substrate
  - Taber abrader, CS-10F wheels, 500g each, 1500 cycles
  - Measure weight loss and haze gain with cycles
Abrasion Resistance – Waterborne Topcoat

Effect of Particles on Taber Abrasion
W/B Low Gloss UV-Cured Topcoat, 1 mil, CS-10F, 500g, 1500 Cycles

- Control
- 40 nm Alumina
- 150 nm Alumina
- 800 nm Alumina
- 7 um Glass Beads

25-40% improvement with 150 and 800 nm alumina
Waterborne Topcoat – Taber, 25 Cycles

Unfilled Control

40 nm Alumina, 1 wt%

150 nm Alumina, 1 wt%

800 nm Alumina, 1 wt%
Alumina Particle Size Combinations

Particle density at 1 wt% loading

150 nm
1 µm
40 nm

800 nm
Scratch Resistance – Waterborne Topcoat

Combinations of alumina particle sizes for scratch resistance

Scratch Resistance of Water-Borne UV-Cure Coating, Low Gloss
2 wt% Alumina, #1 Steel Wool, 100 Cycles, 1 lb weight

No synergy between particle sizes
Effect of Alumina on 100% Solids Coating

- Coating System
  - 100% solids high gloss urethane clearcoat
  - 1 mil dft

- Taber Abrader
  - Drawdowns on clear PET substrate
  - Taber abrader, CS-10F wheels, 500g each, 1500 cycles
  - Measure weight loss and haze gain with cycles
Abrasion Resistance – High-Gloss Clearcoat

Effect of Particles on Taber Abrasion
UV-Cured Clearcoat on PET, 1 mil, CS-10F, 500g, 1500 Cycles

- 40 nm Alumina
- 150 nm Alumina
- 800 nm Alumina
- 5 um Glass Beads

20-25% less weight loss with 150 and 800 nm alumina
Abrasión Resistencia – High-Gloss Clearcoat

Efecto de Partículas en Abrasión de Taber
UV-Cured Clearcoat on PET, 1 mil, CS-10F, 500g, 1500 Cycles

- 40 nm Alúmina
- 800 nm Alúmina
- 150 nm Alúmina
- 5 μm Bolas de Vidrio

Control

50% menos
crecimiento de haz con 150 y 800 nm alúmina
Optimization Parameters

Critical coating requirements:

- **Clarity**: What type of substrate is being used and what degree of transparency is required?
- **Thickness**: What is the final film thickness?
- **Wear**: What level of protection is required; mar, scratch, abrasion?
- **Resin**: What type of flexibility and hardness is demanded in the coating?

Optimize the scratch resistance of the system based on an understanding of the effects of particle size and loading level.
# Optimization in UV-Cured Coatings

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Electronics Coating</th>
<th>Plastics Coating</th>
<th>Wood Top Coat</th>
<th>Matted/ Low Gloss</th>
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<tbody>
<tr>
<td>Clarity Need</td>
<td>Very High</td>
<td>High</td>
<td>Low</td>
<td>Very Low</td>
</tr>
<tr>
<td>Thickness</td>
<td>Thin</td>
<td>Thin</td>
<td>Thick</td>
<td>Variable</td>
</tr>
<tr>
<td>Wear Type</td>
<td>Scratch</td>
<td>Scratch</td>
<td>Abrasion</td>
<td>Scratch/Abrasion</td>
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<tr>
<td>Resin</td>
<td>Very Hard</td>
<td>Soft</td>
<td>Hard</td>
<td>Variable</td>
</tr>
<tr>
<td>Recommendation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alumina Particle</td>
<td>40 nm</td>
<td>150 nm</td>
<td>800 nm</td>
<td>150-800 nm</td>
</tr>
<tr>
<td>Loading Level</td>
<td>2-4 wt%</td>
<td>0.5-1 wt%</td>
<td>1-2 wt%</td>
<td>1-3 wt%</td>
</tr>
</tbody>
</table>
Summary

• Submicron alumina particles can be surface-treated to be compatible with waterborne UV-curable coating formulations
• Concentrated dispersions of the treated alumina particles can be prepared in water or acrylate monomers
• The alumina particles provide scratch and abrasion resistance at relatively low loading levels (1-5 wt%)
• Overall performance requires optimization of particle size and weight loading based on:
  - Clarity requirements
  - Coating thickness
  - Resin Type
  - Degree of wear resistance desired
Thank You

For additional company and product information please visit our booth or contact…

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