Automotive Coatings Defects

Part 2: Weathering Processes and Their Effects on Coating Properties

by **Clifford K. Schoff**
Schoff Associates.*

This paper continues the discussion of weather-related field defects and problems in automotive coatings begun in Part 1.† It describes changes in the properties of coatings such as fracture energy, hardness, glass transition, and barrier properties on weathering, and presents techniques that can be used to characterize a number of these changes. It describes the effects of weathering on various defects and discusses root cause analysis of field problems. It raises the possibility that important root causes of cracking, stone chipping, and mar and scratch problems may be in-plant repairs and overbaking.

INTRODUCTION

It is well known that weathering has a considerable effect on coatings, the chemistry and extent of which vary with conditions and the technology. Weathering of coatings can cause photooxidation, hydrolysis, additional crosslinking, bond breaking, erosion, and loss of the UV package (loss and migration on bake is a greater problem). These changes, in turn, cause changes in mechanical properties such as increased brittleness as shown by decreases in the energy to cause fracture. Hardness increases, but toughness (area under the stress-strain curve) tends to decrease. The glass transition temperature (T_g) of the coating usually increases as does the internal stress. The coating tends to become thinner and denser. The barrier properties usually degrade as photooxidation occurs and pinholes and cracks form. Water and ion transport increases (more, faster) and electrolyte builds up at the metal-water interface, possibly leading to corrosion and blistering.

CHARACTERIZATION OF COATINGS

A number of techniques have been used to characterize the effects of processing and weathering on coatings. Fracture energy and fracture toughness

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*4736 Magnus Dr., Allison Park, PA,15101.
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have been studied extensively by Nichols and coworkers at Ford.[1-3] *Figure* 1[1,2] shows an example of their results where fracture energies for three acrylic-melamine clearcoats varied considerably before weathering and decreased with weathering, but the rank order changed. The lower fracture energies indicated a greater likelihood of cracking. Plots A and B give an example of the kind of crossover of properties that can occur with weathering.

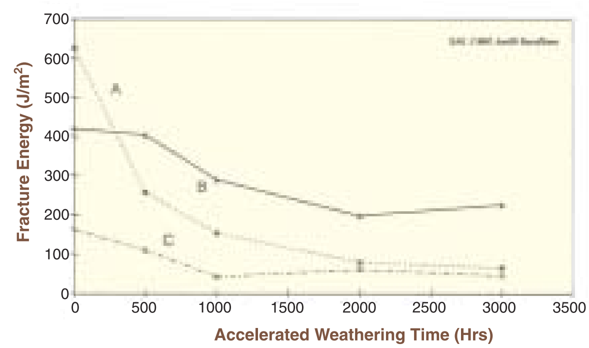
In my former laboratory, Nichols' technique was used to look at the effect of extra baking on the fracture energy of three acrylic-melamine clearcoats as shown in *Figure* 2. The hard acrylic clear was brittle and consistently had the lowest fracture energies. It was more apt to crack with additional bakes and also had poorer scratch resistance with time on exposure. The carbamate clear had the highest fracture energies and best properties.

Another way to characterize weathering is to follow the increase in T_g and crosslink density with exposure. This can be done using a dynamic mechanical thermal analyzer (DMTA) to measure storage modulus and loss tangent,[4,5] but that requires free films or flexible substrates. An instrument that is almost unknown in the United States, but well-suited to following changes in glass transition, is the Rheovibron DDV-OPA III, often called the F-DOM (free damped oscillation method). This is a Japanese device[6-8] based on the same principle as pendulum or rocker hardness measurements (Persoz or König hardness). A new version of the instrument recently was introduced to the U.S. market by another manufacturer.[9] The pendulum used for following cure of a wet paint is shown in *Figure* 3. The pendulum used for monitoring changes in glass transition has a cylinder in contact with the coating surface rather than a knife edge.

Measurements can be done on coupons cut from panels or even from a car hood or deck lid. The damping of the rocking motion on the surface of the coating is measured repeatedly as the temperature of the coupon is increased. Changes in the damping peak that defines the T_g can be followed as a function of weathering, bake time and temperature, etc. *Figure* 4 compares the damping characteristics of an acrylic-melamine clearcoat over a solventborne basecoat exposed in Florida for two years (the deck lid of a car) and that of an unexposed control. The exposed specimen exhibits a shoulder in the region of the control T_g peak (~65°C), but has a new peak at a higher temperature (~90°C). The exposed coating showed microcracking and a loss of gloss.

Because the exposed coating had a higher T_g than the control, a question arose as to whether the exposed coating had been overbaked when the car was painted. This also would be expected to give a higher T_g.

Figure 1—Fracture energy, G_c, of three acrylic-melamine automotive clearcoats as a function of accelerated weathering time. The weathering conditions were from SAE method J1960 Jun89 with borosilicate inner and outer filters.



Therefore, a portion of the control specimen was cycled up to 160°C, cooled, and tested. The damping plots shown in *Figure* 5 indicate that high temperature produced a different result from exposure. Overbaking only gave one T_g at ~ 90°C. It did not leave a shoulder at the original T_g as did exposure. Therefore, it was concluded that the changes in the coating on the deck lid were due to exposure, not overbaking.

Other techniques that have been used to study the effect of weathering on the properties of coatings include contact angles for following changes in solid surface tension, differential scanning calorimetry, characterization of surface topography, and FTIR analysis.[5]

Effect of Weathering on Defects and Problems

Although blistering occurs with precipitation, I do not recall seeing blisters on weathered vehicles or panels unless they were the result of corrosion. Reducing the barrier properties of a coating means water passes through the coating more easily, but it also gets out more easily. With regard to blistering, there may be an advantage in a coating becoming a microsponge.[10]

Figure 2—Change in fracture energy of three automotive acrylic-melamine clearcoats with additional cycles through the topcoat oven

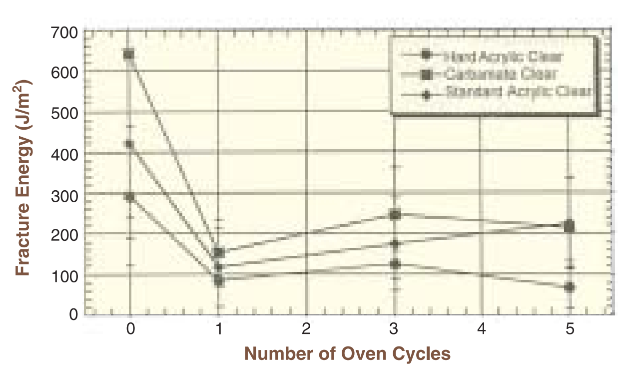
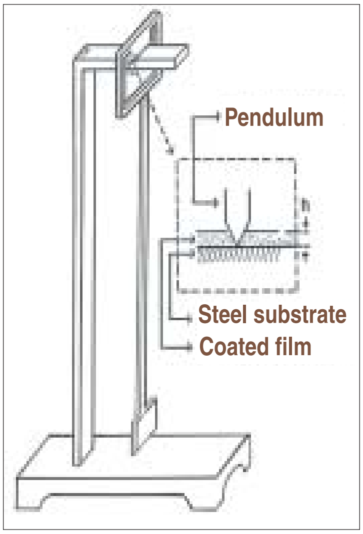


Figure 3—Diagram of the F-DOM apparatus.

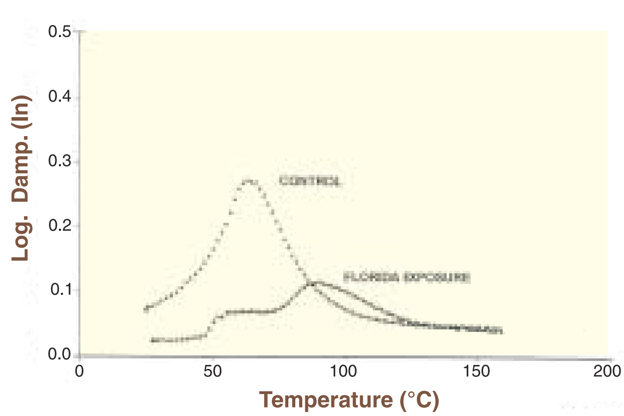


Weathering can cause water spotting, but as gloss decreases, water spots become less noticeable. Acid etch is a direct result of weathering that includes acid precipitation. Etch harms appearance, but it also can threaten protection because stresses can concentrate at etch spots and cause cracking. There have been many cases where cracking was associated with etch spots.

The temperature and humidity cycling involved in weathering can increase stress[11-15] at the same time that degradation processes are making the coating less resistant to stress. A fresh coating may be very resistant to cracking, whereas a weathered coating may not be. Occasionally, very small cracks (microcracks) will release stress with little effect on appearance or protection, but the gloss may be reduced. The increase in stress may lead to a loss of adhesion to a substrate or undercoat.[14] Adhesion also may be lost due to exudation of material from a substrate (for example, plasticizer or mold release migrating from a plastic) or a lower coating layer.

Surface erosion and increasing brittleness on weathering can lead to reduced scratch resistance. I first noticed this with my own cars and had it reinforced when I examined Florida exposure panels that were scratched even though we had tried to handle them carefully. A substantial decrease in scratch resistance can occur in only three months[16,17] and continue to drop for years.[18]

Figure 4—F-DOM damping curves for exposed and unexposed specimens of an acrylic-melamine clearcoat over a solventborne basecoat.



Until recently, auto companies only required testing of fresh panels, but they have begun to realize that good initial mar and scratch resistance may not mean good resistance after a few months. Acrylic-melamine clearcoats have excellent initial scratch resistance, but lose this resistance rapidly with weathering. Other chemistries (2K polyol-isocyanate, epoxy-acid) have a moderate resistance to begin with, get better for a few months, and then begin to lose resistance.[16,17]

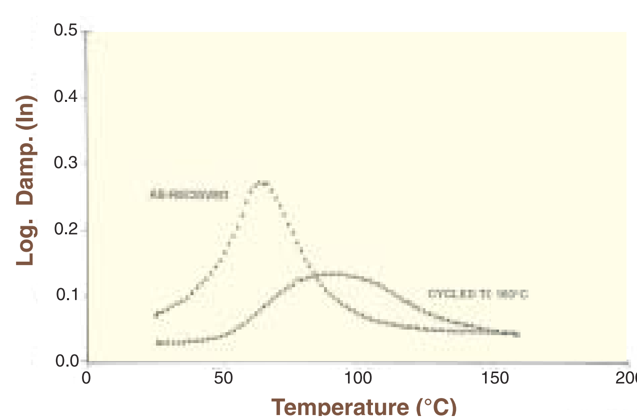
Retained mar and scratch resistance is even more important than initial resistance. Therefore, it is necessary to test panels after various periods of aging. There are a number of mar and scratch tests,[19] many of which are more abrasion tests than scratch tests. However, there is a movement towards measuring basic mechanical properties such as the stress necessary to initiate a scratch and scratch depth as a function of stress (which could be called scratch modulus).[20-22]

Chip resistance depends on the mechanical properties of the layers and the adhesion between them. Degradation and embrittlement with exposure can lead to more surface damage from stone impacts, but may or may not make the chip rating worse. It may well change the locus of failure to one of the upper layers. Stresses in the coating probably affect chip, but little is known about the relationship. Certainly it would seem logical that a highly stressed coating would be more likely to respond to being struck by a stone by cracking or chipping.

Root Cause Analysis of Field Problems

Root cause analysis is a powerful tool that is relatively new to those who work on coatings defects and problems in North America. It has been used in Japan for many years. Root cause analysis is the determination of the basic or underlying cause of a defect or problem. It consists of identifying the cause and prov-

Figure 5—F-DOM damping curves for unexposed clearcoat/basecoat specimens baked at 141°C (as-received control) and cycled to 160°C (overbake).



ing that it indeed is the cause. If done correctly, then the countermeasures taken should guarantee that the problem does not happen again. It normally requires more discipline, experimentation, and documentation than is usual in problem solving in North America. It is particularly useful for applying information learned from customer complaints and warranty claims to the improvement of the painting process.

Many automobile owners accept field defects as normal wear and tear, especially after a year or so. However, when an owner does complain and asks that repairs be carried out under warranty, the claim often is investigated to determine legitimacy and to see whether there is or was a production problem. The investigator must determine whether the defect or problem is due to one or more of the following:

- Misuse of the vehicle;
- Insults beyond the capability of a paint to withstand (such as being bashed by a grocery cart);
- Vehicle design (which used to be the cause of many corrosion problems);
- Materials of construction other than paint (rough steel, plastic that is exuding plasticizer, bad pretreatment, no pretreatment, or cold-rolled steel instead of galvanized steel);
- Paint;
- Painting and other processes in the auto plant (very difficult to track down because root causes could include bad work practices, poor maintenance and quality of application equipment, overbaking, underbaking, etc.); May include dirt missed at the inspection and sanding/polishing (finessing) stations and/or in-plant damage;
- Repair; and
- Storage and shipping problems.

I believe that defect repair is a common root cause and that field problems would be reduced if fewer in-plant repairs were made. There is a Japanese concept called "no touch" that teaches that the painting process should be so effective that no repairs or even sanding and polishing are needed. I am convinced that "no touch" is not just a slogan or way of saving on repair costs, but is a key to the prevention of many field problems. Many car bodies can be rated as "no touch," but many others need to be repaired. At this point, I have mostly anecdotal evidence and a few indications of trends as evidence for my indictment of repairs. However, data from four plants (A-D) of one auto manufacturer indicate that there is a correlation between higher levels of chip and scratch and a high percentage of low bake repairs (*Table* 1). All four plants were using the same clearcoat chemistry when the data were collected. Results from the first three plants show a good correlation between all repairs and chip/scratch, but the plant D data do not fit. Total paint warranty

Table 1—Repairs, Defects and Warranty Costs

Plant	*Repair Rate*	*Prop. of Low Bake Repairs*	*Paint Chipped or Scratched (probs/100 units)*	*Total Paint Warranty Cost Factor*
A	High	High	9.4	9.3
B	Medium	Low	5.9	5.0
C	Low	Low	4.4	3.5
D	High	Very Low	4.0	1.0

cost factors (all paint defects that must be repaired, not just chip and scratch) follow the chip/scratch trends.

Plant D seems to disprove my general repair thesis because it has a low chip/scratch level and very low warranty, but a high repair rate (due to meeting very high standards). This plant also monitors and controls the number of bakes and maximum film thickness very carefully. Beyond four bakes or a certain film thickness, the body is scrapped. So, it appears to be possible to carry out high bake repairs without raising warranty costs. This plant avoids low bake repairs (80°C or lower bake with a catalyzed topcoat) if at all possible. Their concern is undercure, which leads to poor resistance to abrasion, scratching, and etch.

At most plants, repairs result in more defects (especially dirt) than the original painting, which leads to additional repainting, more bakes, and very thick films. Cross sections of some defects on repair units look more like layer cakes than paint films! Most plants are not as careful as they should be about limiting bakes and film thickness. Even where repairs do not cause more dirt or other defects that need further repair, they often give a less attractive appearance than the original finish due to increased orange peel.

CONCLUSIONS

Very simply, weathering causes defects in automotive coatings and often attacks clearcoats weakened by in-plant repairs or overbakes. There are indications that a reduction in the number of in-plant repairs may lead to fewer field defects, especially cracking, stone chipping, and mar and scratch. CT

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