Episode Book

EPISODE #5776

Why UV Epoxy Keeps Curing in the Dark

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SYNOPSIS

Daniel asked why epoxy can't cure itself, and whether light can replace the hardener. The answer runs through a three-membered ring under strain, a hardener ratio where a few percent decides the repair, and a photoinitiator that generates acid instead of radicals. That last detail is why true UV epoxy cures in shadows no lamp can reach — and keeps curing for a day after the light is off. We cover the basic two-part chemistry first, then dig into cationic curing, the craft-store resin mix-up, oxygen inhibition, and the datasheet numbers that show a UV-cured joint nearly tripling in strength overnight.

TRANSCRIPT



Corn

Ninety-eight percent. That's the share of every epoxy on the planet that comes down to one molecule.



Herman

Diglycidyl ether of bisphenol A. And everything else in the bottle is basically a supporting actor.



Corn

Daniel wants to know why that molecule can't just cure itself, and whether shining a light on it solves the problem.



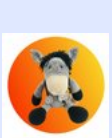
Herman

Right. Last time we compared superglue and epoxy, landed on epoxy as the stronger performer, and I believe the word "messier" came up.



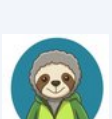
Corn

It did. He's been interested in UV-cured epoxy for a long time, wanted to know how it works, how long it actually lasts, what to look for in a curing light, and whether it can rescue a broken ceramic light fixture.



Herman

And he asked for the basic chemistry of traditional epoxy first. Why the mixing, what the two components actually are.



Corn

So before we get to the light, let's do the mixing.



Herman

The two-tube syringe is the place to start, because most people have used one without ever thinking about it. You push the plunger, two pastes come out, they go through a little corkscrew nozzle, and thirty seconds later you've got something that will hold a car door on.



Corn

That corkscrew is the part people get wrong.



Herman

It's a static mixer. No moving parts. The geometry of the baffles inside does the blending, and it only works if the two streams arrive in the right ratio and get folded into each other enough times. It's doing stoichiometric blending in real time, in a nozzle that costs about a dollar.



Corn

Stoichiometric being the word that decides whether your repair holds.



Herman

Completely. The rule of thumb is one to one by reactive groups, and the CKN composites knowledge base puts a blunt number on it, that cured properties vary dramatically with only a few percent deviation from the exact stoichiometric amount.



Corn

A few percent. Not a few grams, a few percent.



Herman

That's where the failure mode lives. People squeeze a bit more hardener in because it feels thin, or they skimp on the hardener because it smells strongly, and they end up outside the window. Too much epoxy and you get better water and acid resistance but a more brittle, under-crosslinked network. Too much amine and you get more flexibility, but



Herman (continued)

the unreacted amine sits in the cured material doing nothing helpful.



Corn

What is the epoxy group actually? The thing that does the reacting.



Herman

It's a three-membered ring. A cyclic ether, an oxygen bridging two carbons, and the ring is strained because of the geometry. Three atoms in a ring want to be at roughly a hundred and nine degrees and they're forced much tighter than that.



Corn

So the ring is basically holding a spring under tension.



Herman

That's the whole game. The oxygen is electronegative, it's pulling electron density away from the carbons, and the ring angle is wrong. Thermochemically it just wants to open. All you need is something on the other end willing to attack it.



Corn

And the workhorse molecule that carries those rings is DGEBA.



Herman

Diglycidyl ether of bisphenol A. Reaction product of bisphenol A and epichlorohydrin. Two epoxide groups hanging off either end of a bisphenol A core.



Corn

Bisphenol A being the part everyone recognizes from the plastic bottles.



Herman

Two phenol groups joined through an acetone unit. And the numbers here are striking. Something on the order of ninety-eight percent of all commercial epoxies are bisphenol A based. Everything from the hardware store two-part to the aerospace prepreg.



Corn

So one molecule from 1938-ish is still carrying the entire industry.



Herman

It's a good molecule. The ring system gives you the reactivity, the aromatic core gives you rigidity and heat resistance, and the ether links give you flexibility. It's very hard to beat with a single other monomer.



Corn

Part A is DGEBA with a bunch of epoxide rings bristling off it. What's in Part B?



Herman

The hardener. Also called the curing agent. Most commonly an amine. And here's the part that I think is elegant, that makes epoxy what it is instead of just a nice plastic.



Corn

Go on.



Herman

A primary amine has two active hydrogens on the nitrogen. The first one opens an epoxide ring on one resin molecule. Now the amine has one left, and it reacts with a second resin molecule. And when that first ring opens, it turns that epoxide into a secondary amine.



Corn

Meaning the reaction products themselves are reactive.



Herman

Every time the epoxy group opens, it creates a new hydroxyl group on the chain. Those hydroxyls can participate in the network and they're what give epoxy its adhesion. But also the original amine becomes a branching point. One molecule now has two arms, and each of those arms has a new amine on the end.



Corn

Which can react with two more.



Herman

And those with two more. If it were a linear chain you'd end up with something like polyethylene, chains sliding past each other, melting when it gets hot. What you actually build is a three dimensional network where every chain is chemically tied to every other chain.



Corn

That's why you can't melt it. Once it's set, it's set.



Herman

Thermoset versus thermoplastic. That's the distinction. It's not a solvent drying out of a gooey adhesive. It's a liquid being converted into a single molecule that happens to weigh a pound.



Corn

And you can't take that back.



Herman

Cure is irreversible. CKN puts it as viscous liquid, to rubbery gel, to glassy solid. You can't un-stir it. Shrinkage on cure is typically two to seven percent by volume, which is why you can get visible sink at the edges of a big pour.



Corn

So the reason it needs mixing is that it's a chemistry reaction, not an evaporation. Both components actually need each other.



Herman

Neither does anything alone. The resin has the rings but nothing to open them. The amine has the hydrogens but nothing to attack. Put them together and the reaction goes, and it goes fast. That's why you have a pot life. A couple of minutes on a fast formula, half an hour on a slow one.



Corn

Sometimes the box says twelve months shelf life.



Herman

Twelve to twenty-four months for the unmixed resin is the usual range. Stored cool and away from moisture. And there's a nice failure pattern where it crystallizes, below about twenty-five degrees C, and people think the bottle is ruined, and it's fine, you just heat it gently to fifty degrees C and the crystals melt back in.



Corn

Which sounds like a warning on the side of a honey jar. Put it in warm water, walk away.



Herman

That's exactly what it is. And the glass transition temperature range across all epoxies is enormous. One degree C at the low end for the rubbery stuff, two hundred and eighty-five for the high-temperature aerospace grades. Average around a hundred and twenty-three.



Corn

So the two-part system is a controlled chemical reaction that starts when you decide to start it, and you have to get the ratio right. The mess isn't a design flaw, it's the price of the chemistry.



Herman

The mess is the chemistry. Which is what makes Daniel's question interesting, because what if you could trigger the reaction with something other than a hardener?



Corn

A photon instead of a molecule.



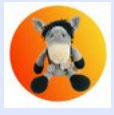
Herman

That's UV curing.



Corn

And this is where the shops have been lying to everyone for years.



Herman

I want to draw a hard line before we go further, because Daniel specifically said UV cured epoxy, and that is not the same thing as what the craft store sells as UV resin.



Corn

The little bottles in the jewellery aisle.



Herman

Those are almost always a radical cured acrylate. Acrylate chemistry, cured by free radical polymerization. That's the same family as your nail polish lamp, and the same physics, and it has two properties that matter.



Corn

The first being oxygen.



Herman

Oxygen inhibition. The oxygen in the air at the surface of the resin scavenges the free radicals before they can do anything. That's why your UV resin project comes out of the light with a sticky film on top. You're supposed to wipe it with alcohol. That film isn't leftover resin, it's resin that couldn't cure because there was air in the way.



Corn

And the second one?



Herman

Radical systems stop when the light stops. Take the piece out from under the lamp and the reaction is finished. Whatever didn't get photons stays liquid, or gels badly, and if there's a shadow under the piece you've got a wet spot you can't see.



Corn

Whereas the epoxy family goes a different direction.



Herman

True UV cured epoxy is a cationic system. The photoinitiator doesn't split into free radicals. It splits into a strong acid. Specifically, the classic initiator here is a diaryliodonium salt, and it was Crivello in 1977 who established that you could get these to photodecompose into a Brønsted acid when hit with UV.



Corn

A Brønsted acid meaning a proton donor. It's just an acid.



Herman

And in this case the acid is the thing that opens the ring. Same reaction as the amine, different attacker. And two properties fall out of that. First, oxygen can't scavenge an acid, so oxygen inhibition cannot occur. Surface comes out tack free. Second, and this is the important one, the acid doesn't get consumed the way a photon does. Once it's generated, it keeps working.



Corn

Even after the light is off.



Herman

That's dark cure. Shadow cure. The polymer network keeps growing in the dark, using the acid that was generated while the light was on. Millions of chain propagation steps that happen in a room with the lights off, underneath the component you're trying to glue.



Corn

So the reason this works for electronics is that a conformal coating can be cured on a board where half the board is underneath chips.



Herman

Hoenle describes it exactly that way. The edges and the visible surfaces cure with UV, and the shadowed areas underneath the components get post-cured by heat, or by the dark cure. Master Bond sells dual cure formulations that are specifically made for this, where the UV fires the reaction and the heat finishes it.



Corn

So a chip on a board has a little shadow cave underneath it, and the coating in that cave has to cure without any light reaching it.



Herman

Two mechanisms. First the cationic dark cure from the acid that got generated through the light path. Second, the board goes through an oven or a heat soak later, and that finds the last unreacted groups.



Corn

That's clever. Chemical shadow work.



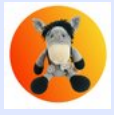
Herman

And it's also the reason electronics people don't just use a radical acrylate for this. The acrylate would stop dead at the edge of the chip, and underneath you'd have uncured goo forever.



Corn

Now here's the bit that surprised me when you sent me the datasheet, because there's a second dark cure and it takes a day.



Herman

Correct, and I think this is the best single number in the whole episode. EPO-TEK OG116-31, a single component UV epoxy, die shear strength after UV cure alone is ten kilograms, three thousand five hundred and fifty-six psi. After UV cure plus twenty-four



Herman (continued)

hours at room temperature it's twenty-seven point eight kilograms, nine thousand eight hundred and eighty-five psi.



Corn

Nearly triple.



Herman

The datasheet actually spells it out. UV cure is complete after twenty-four hours from UV exposure. Meaning the light gets you to a green state, and the ambient cure is what gets you to full strength.



Corn

So the instant cure is not instant.



Herman

The instant cure is fast enough to handle the part. Which for a production line is really what you need. You UV the part, it's hard enough to move to the next station, and then it keeps getting harder for a day. Everyone who's ever built something with it knows the habit of leaving it overnight before load testing.



Corn

This is the thing I want to push on. If you're an assembling line, that's a scheduling problem. If you're doing a home repair on a ceramic light fixture, that's the difference between fixed and looked fixed until it isn't.



Herman

And it's why the datasheets list two cure numbers. The initial UV dose gets you a firm cure. The full cure is UV plus ambient time.



Corn

Let's do the how long question properly, because Daniel asked it and it has two meanings.



Herman

It does. Shelf life and cure time. On shelf life, OG116-31 is one year at room temperature, both bulk and syringe. UV2016 from United Adhesives is also at least twelve months, sealed and away from UV. The rule is simple. Keep it sealed, keep it in the dark.



Corn

If you leave a UV adhesive on a windowsill.



Herman

You come back to a solidified tube. The room light has been slowly curing it the entire time.



Corn

Now cure time on the job.



Herman

OG116-31 under an iron-doped mercury flood lamp at a hundred milliwatts per square centimeter, thirty seconds. Under a 365 nanometer LED flood lamp, more than two and a half minutes. Pulsed mercury lamp, more than sixty seconds. Iron-doped mercury spot lamp, more than five minutes.



Corn

So the same adhesive has a cure time that varies by an order of magnitude depending on the lamp.



Herman

Which is the whole game. It's not a fixed property of the adhesive. It's the interaction between the adhesive's photoinitiator and the lamp's wavelength and irradiance. Irradiance times time equals dose, in millijoules per square centimeter. That's the actual quantity doing the work.



Corn

And it doesn't matter what the label on the lamp says.



Herman

It barely matters. Which is the question Daniel asked about bad quality lamps, and the answer is sobering. Craft Resin, who sell consumer UV resin lamps, put out a piece warning that many low-cost lamps inflate wattage numbers or use inefficient LED layouts. The published watt figure can be the total power drawn by the lamp at the wall, not the power arriving at your work surface.



Corn

So the number on the box is the input, not the output.



Herman

And the light has to get to the surface through the lens, through the LED's own phosphor, off a reflector, and out. A cheap lamp with a weak reflector and an inefficient PCB layout can lose the majority of its output before it reaches your joint. And that loss doesn't show up in the spec sheet.



Corn

What actually matters then.



Herman

Irradiance at the surface in milliwatts per square centimeter, multiplied by the exposure time. Plus even coverage across the whole cure area, plus a reflective interior so light bounces back in, plus power delivery that doesn't sag as the lamp heats up. Cheap lamps sag in output over the course of an hour. If you're setting the cure time off the cold-lamp number, your last parts of the day are undercured.



Corn

So the honest advice is a radiometer.



Herman

A radiometer at the cure point. Poly Dispensing calls it the same thing, measure actual UV output with a calibrated radiometer, recalibrate annually, because the LEDs drift with age even on good lamps. The industrial units like the OmniCure LX500 hold stability within plus or minus five percent, and can put out something like twenty-eight watts per square centimeter at three hundred and eighty-five nanometers. The kitchen-table version can't do either.



Corn

Now the wavelength part, because this is where Daniel is going to get an unpleasant surprise on his first purchase.



Herman

INCURE puts it bluntly. Wavelength selection is not a preference, it is a photochemical requirement. Choose correctly and the adhesive cures completely and repeatably. Choose incorrectly and you may spend weeks troubleshooting what looks like a dispensing problem that is actually the wrong photons hitting the wrong photoinitiators.



Corn

That's a spreadsheet and a bad afternoon.



Herman

The four standard UV LED wavelengths are three sixty-five, three eighty-five, three ninety-five, and four oh five. Three sixty-five matches the mercury i-line historically, but the LEDs are relatively inefficient at that wavelength, less output per watt. Three ninety-five is the industrial workhorse, good output and good coverage. Four oh five is efficient and penetrates best, but some free radical photoinitiators cure poorly there.



Corn

So the wavelength on the lamp has to match the wavelength on the adhesive datasheet.



Herman

The datasheet is the primary source. The adhesive maker specifies the photoinitiator and the recommended wavelength. The rule among the dispensing people is never choose the wavelength arbitrarily, and validate the pairing by application testing before you scale anything.



Corn

Now the failure pattern that makes this scary.



Herman

Wavelength mismatch looks cured. That's the horror. Low surface tack, the part holds together, it survives being moved. But the through-cure is incomplete. The bulk of the adhesive is still liquid or gel, and you can't tell from the outside.



Corn

Until it fails.



Herman

Until it fails under load, or under thermal cycling, or in three weeks when the seasons change. INCURE says the visible appearance of UV-cured adhesive does not reliably indicate cure completeness.



Corn

So add one more thing to the list of products you can't evaluate from the packaging. The adhesive cures regardless of whether it was cured properly.



Herman

That's a lovely phrasing. The adhesive doesn't know.



Corn

What does it look like when it's used well.



Herman

Electronics is the flagship. OG116-31 is designed for PCB and circuit assembly, chip on board glob top covering the ICs and the wire bonds, glob top dams, encapsulating, sealing. It adheres to FR4, to Kapton, to silicon. That's the classic application, you've got a chip that's been wire bonded to a board, and you want to cover the whole thing in a protective dome of epoxy, and you can't heat it because you'd cook the die.



Corn

So you light cure the dome in thirty seconds, and it dark cures underneath the wire bonds where no light reaches.



Herman

That's exactly the model. United Adhesives UV2016 is a flexible version, cures in about thirty seconds under a mercury H bulb at a hundred milliwatts per square centimeter, and it bonds to silicon, BGA packages, ceramics, FR4, LTCC, aluminium, copper, stainless steel.



Corn

So the electronics claim isn't a marketing flourish, it's the use case that drove the development of the chemistry.



Herman

Cationic UV curing exists in part because electronics needed a coating that would cure in the shadow of a component. The dark cure isn't a bonus, it's the reason the whole family exists.



Corn

Now the ceramic light.



Herman

Right. Daniel's specific question. And the honest answer is a genuine maybe, with caveats.



Corn

Start with the good news.



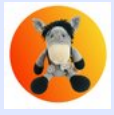
Herman

Both of the datasheets we've been citing list ceramics as a substrate. OG116-31 adheres to many types of glass, metals, ceramics and plastics. UV2016 bonds to ceramics as one of its listed materials. So the chemistry itself is fine with ceramic.



Corn

And the bad news.



Herman

There's no published guidance on UV epoxy as a structural ceramic repair. Nobody has tested that as a standard use case. It doesn't mean it can't work, it means you're on your own for the joint design.



Corn

The shadow problem again.



Herman

If the two pieces of ceramic fit tightly, and the crack is a hairline crack, most of the adhesive is in a line-of-sight thin layer, and UV from the outside is going to reach most of it. That's a case where it can work. But if the crack is deep, if the joint has any thickness, if the ceramic is opaque or dark, UV doesn't penetrate in behind the surface. Everything more than a millimetre inside the joint stays liquid.



Corn

And you can't see whether it's cured in there.



Herman

You can't see whether it's cured in there. The outer surface will be rock hard and the inner joint will be wet, and you'll find out when the piece falls apart.



Corn

So Daniel's ceramic light is actually two different questions depending on the geometry.



Herman

Correct. Shallow surface crack on a white ceramic piece, two surfaces that fit back together perfectly, and a lamp shining into the joint from both sides, that's the best case. UV epoxy could plausibly hold a light fitting there. Deep crack in an opaque piece, no line of sight to the interior, no way to heat-cure because it's ceramic not a PCB, and the honest answer is you probably want a two-part epoxy instead. Same chemistry family, mixed by hand, cures everywhere.



Corn

Because the mixing inconvenience is precisely the mechanism that gets around the shadow.



Herman

The mixing inconvenience is what makes it cure in the dark without light or heat. Part A and Part B can find each other anywhere in the joint. UV-cured epoxy needs either photons or the dark cure from acid that was generated by photons that reached it. No photons, no dark cure.



Corn

There's something quite elegant about that. The reason UV epoxy is convenient is the reason it has a blind spot.



Herman

And the reason the two-part stuff is annoying is that it works in a bag, a breadcrust, anywhere.



Corn

One practical thing before we wrap the chemistry.



Herman

Go on.



Corn

The little UV epoxy kits that come with a pen-style 365nm lamp and a syringe. Where do they sit?



Herman

Fine for small, shallow, line-of-sight jobs. Optical bonding, small lens seats, gluing a metal fixture to glass. The gotcha is if you buy a cheap lamp with no wavelength spec, you may be buying a 395 or 405 lamp that was never formulated for these adhesives. My advice is buy the adhesive from a source that publishes the photoinitiator and the wavelength, and buy the lamp from a source that publishes the wavelength and the irradiance.



Corn

Not the watts.



Herman

Irradiance and wavelength or walk away.



Corn

What about dual-cure formulations?



Herman

The dual cure is the practical compromise. UV for the visible surface, heat for the shadow, and both mechanisms share the same photoinitiator family. It's why conformal coatings in aerospace and automotive tend to be sold as dual cure rather than pure UV. There's no point pretending light reaches everywhere on a populated PCB.



Corn

Nor on a ceramic light.



Hilbert

I don't think a single one of them ever trusted the light alone. Not once.



Hilbert

I worked a warehouse job, the summer of seventy-nine, and we were doing a contract for a company that made instrument meters. Cheap ones. Big plastic bodied things with a needle and a faceplate. Every unit came back for a faceplate replacement at some point, and the replacement procedure used a UV-cured adhesive. Little tube on a syringe, and a lamp shaped like a hairdryer. Push the plunger, hold the lamp two inches off the faceplate for about thirty seconds, that was the whole thing.



Corn

And the folk knowledge?



Hilbert

The supervisor was a woman called Rose, and she had a rule. Everything that came off the light went in a rack at the back of the room for twenty-four hours. No exceptions. Somebody asked her once whether that was really necessary, and she said the ones that went out the same day came back. She kept a tally in a little book. She'd been doing it that way for years.



Corn

So the "wait overnight" habit predated the datasheet language.



Hilbert

The datasheet language came later. The waiting habit came from getting burned. She had a two-week stretch back around seventy-eight where seven units came back on warranty and she spent a month trying to work out why, and the answer turned out to be that the lamp's reflector had gone cloudy and the output was maybe half what it used to be. She couldn't see it, because the lamp looked the same.



Corn

The lamp looked the same but the cure didn't happen.



Hilbert

The adhesive looked the same too, when she took the unit out of the fixture. Hard and clear. Held the faceplate fine. Failed two weeks later when the customer tipped it sideways and the plate slid out.



Corn

A creep failure.



Hilbert

She kept a second book after that one, one line per unit, the lamp number it was cured under, and the date and the shift. She retired in eighty-nine and I think the second book was full.



Corn

That book is a radiometry log with worse handwriting.



Hilbert

It was a notebook from the shop. Spiral bound. Ninety-nine cents.



Corn

Did you ever test the lamp yourself?



Hilbert

I held my hand under it once to see how hot it got, and got a burn on my wrist that took a week to heal. I did not do that again.



Corn

What happened to the notebook?



Hilbert

I don't know. I left the job in August. The plant closed a few years later. I imagine the book went in a skip.



Corn

There's something we should build on there, because Hilbert just described the failure pattern the datasheets warn about, thirty years before the datasheets said it.



Herman

She had it exactly right. Screen and dark cure are the same phenomenon. She'd arrived at the same conclusion as a Crivello photoacidity mechanism by way of warranty returns, and the bookkeeping matched. If your process has a known failure pattern with a delay, you develop a log. If you don't have a log, you find out about the lamp drift when the customer does.



Corn

The cheap lamp warning gets a lot less abstract when you picture a cloudy reflector and seven returns.



Herman

And the reason that problem is invisible is that the lamp manufacturer doesn't measure output. They sell you a lamp. If the reflector ages and the lamp loses half its output, nothing tells you.



Corn

It also puts the ceramic light question in a different light. Daniel is doing one repair, not a thousand units, so he only needs it to work once. But it has to work once at the joint he actually has, and the joint he actually has is the joint he can't see into.



Herman

Correct. The industrial solution for opaque joints is the dual cure. UV for what the light reaches, heat for what it doesn't. Ceramic is about the worst case for heat cure because you can't put the thing in an oven and you can't microwave it and you can't hot-air-gun it without cracking the glaze. So you're left with the two-part epoxy, which cures everywhere without any light or heat at all.



Corn

The ceramic light is a two-part epoxy job, not a UV one.



Herman

Unless the crack is a hairline near the surface, in which case UV epoxy is fine. The honest answer really is it depends on the geometry.



Corn

Here's what I keep coming back to. If UV epoxy's real cure is a twenty-four-hour dark reaction, is any of this actually convenient, or have we just moved the wait somewhere less visible?



Herman

Both, and I think that's the right way to say it. The wait didn't disappear. It moved. For a production line that's a good trade, because you only need the part hard enough to move to the next station, and the rest of the cure happens while it sits in a tray. For a repair you care about, it's the same wait dressed differently.



Corn

The ceramic light question is open in the way that a lot of real engineering questions are. The adhesive bonds ceramics. The light has to reach the joint. Those two facts are true, and they don't tell you whether your particular crack will hold.



Herman

Which is the answer people hate and need.



Corn

As UV adhesives spread into more consumer products, the gap between "looks cured" and "is cured" gets bigger, not smaller. Somebody's going to buy a cheap lamp at a home store next year and fix something with it, and the thing will hold until it doesn't.



Herman

The people who learn what wavelength and dose actually mean will be the ones who don't get burned.



Corn

On that, if you've enjoyed this one, a review wherever you're listening does more for us than you'd think. Word of mouth is basically the whole marketing budget.



Herman

Thanks as always to our producer, Hilbert Flumingtop. Corn: This has been My Weird Prompts.



Herman

The human-AI collaboration podcast. We'll be back soon.



Corn

See you tomorrow.