Built Board Tough

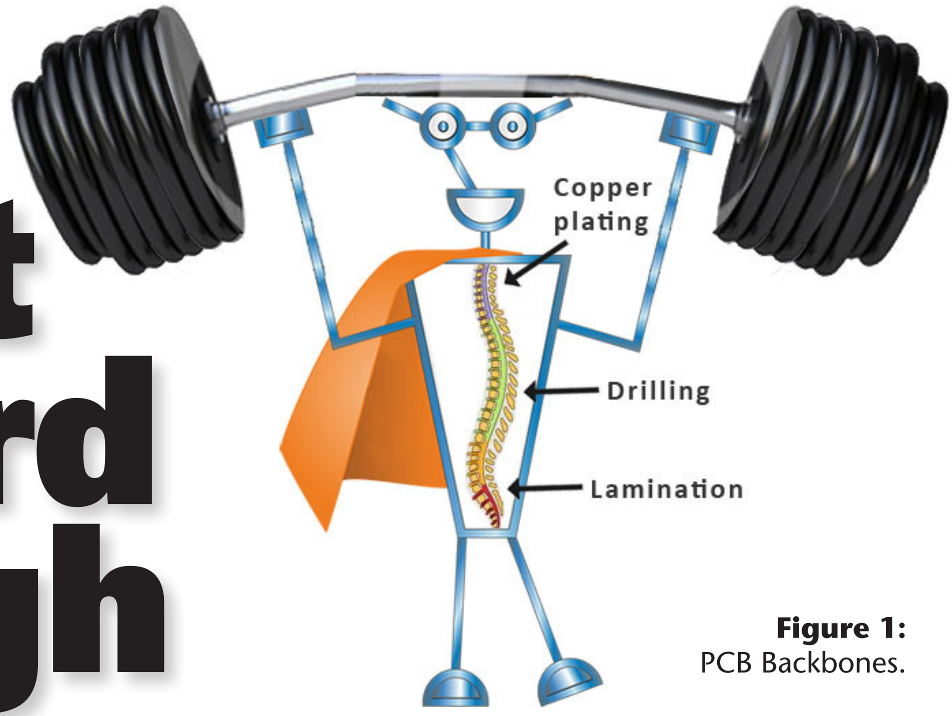

Figure 1: PCB Backbones.

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Summary: *PCBs are electronic real estate. Establishing the foundation for assembly, there is a direct correlation between the reliability of a final electronic product and the bare printed circuit board. There is much to knowing what it takes as both a buyer and a producer of PCBs to ensure high-reliability PCB performance.*

What is PCB reliability and how can we test for it?

Simply put, PCB reliability is the length of time a PCB functions under a given set of conditions (often denoted as "via life"). Typically, the most intensive tests focus on via hole-wall reliability. The following tests are the most commonly used.

Air-to-Air Thermal Cycling

This testing attempts to simulate real operating conditions of the PCB by applying temperature cycling to daisy chain coupons. Each coupon contains a series of vias linked to each other through plated vias and inner layer connections. The test qualifies the vendor based on layer count and minimum via diameter. Testing is performed using two air-to-air test chambers. Standard parameters are five minutes transition time between peak temperatures, and 25 to 30 minutes at peak temperatures. Measurements are performed five times during the process, which terminates at 1000 cycles. Needless to say, this is not a quick test.

Figure 2: Barrel crack.

Highly Accelerated Thermal Shock (HATS)

The HATS test simulates the thermal cycling testing requirements by using an air-to-air thermal cycling procedure that rapidly heats and cools the test vehicles to the minimum and maximum temperatures by using a single chamber and introducing heated and cooled air. The benefit of this method is that it requires approximately 1/6 to 1/7 the time required for the C7000 testing.

Interconnect Stress Test (IST)

IST is another accelerated method of testing. Rather than using an air-to-air method to bring the test vehicles to temperature, this test method relies on an electrical charge to heat the coupon and stress the vias.

The main difference between these tests is how they attempt to stress the test vehicles. The main commonality is that they measure reliability based on resistance measurements of the daisy-chained vias after thermal exposures.

What are the key inputs to PCB Reliability?

Ensuring your bare board continually performs throughout the product's life expectancy relies on PCB production processes that serve as the backbone processes to PCB reliability. These are led by lamination of materials, drilling hole-wall quality, and copper plating characteristics.

The Backbone

How can a PCB manufacturer achieve reliability and how can a buyer audit to ensure high-reliability PCBs?

Knowing the high-level details of critical processes and their effect on other processes is paramount to ensuring bare board reliability. This applies to both the fabricator and the consumer of PCBs. What follows is a high-level discussion of key processes that directly ensure success or failure in the production of high-reliability PCBs.

Figure 3: Lamination Room.

Lamination of Materials

Manufacturers' resin systems have their own optimum parameters for multilayer lamination, or pressing together of multiple layers of circuitry. The bond sheets, known as prepreg, are made of partially cured epoxy. Under the right temperature and pressure, the epoxy melts to contact opposing innerlayer cores, and then sets to a final cure to make the stackup of individual materials into a single unit.

The basics of curing PCB materials include:

1. Rate of rise
2. Cure temperature
3. Time at cure temperature

It's common in the industry for fabricators to use a one-size-fits-all approach to lamination recipes that control the above parameters; however, recipes should be dialed in to the specific brand of resin system. Aiming for the nominal set point ensures a wider process window for resin cure. If the resin is overcured or undercured, subsequent processes may not have the desired effect.

Overcured resin is more brittle, which can result in rough hole-wall quality in the drilling process. As we know, one of the key drivers to PCB reliability is the quality of via connections throughout the PCB. On the other hand, undercured resin can result in excess smear at drilling, and perhaps even delamination in subsequent processes such as hot air solder leveling or final component assembly—also undesirable effects.

We've found the best way to control and continually verify lamination parameters is through the use of a PLC-controlled lamination press. This type of control allows the process engineer to enter in a set recipe to control the critical parameters. Some control systems allow for the use of continuous temperature monitoring via thermocouple. This allows for not only continual monitoring of the package during lamination, but the data can also be saved for use as part of a QC package for that build.

If the press does not have built-in thermocouples, recipes can always be verified periodically by using manual handheld thermocouples. Regardless of the method, actual temperature verifications of lamination recipes are paramount to building high-reliability PCBs.

Upon initial set-up of a recipe, test vehicles should be tested for cure through:

1. Delta T_g testing
2. Time to delamination
3. Copper peel strength

Once a recipe passes these tests (and/or any others deemed critical by the user and supplier) it can be certified for continued use.

Drilling Hole-Wall Quality

Hole-wall quality depends on two key items:

1. Quality and consistency of drill tools
2. Drilling parameters and controls to ensure they are used

Drill Tool Repointing

When we started performing tests to qualify new suppliers, we found that the hole quality of new drill bits was fairly consistent between suppliers when we used their recommended parameters. It was when we tested the repoints that differences in hole-wall quality became evident. Upon further investigation, we found a great disparity in the way different suppliers repointed (or resharpened) drill bits. The industry standard for many years has been to manually resharpen drill bits under magnification using a grinding wheel. This works fine for larger tool sizes, but proves to be difficult for microvias (0.012" and less in diameter).

Figure 4: Drill-hole.

I was auditing a potential supplier in China for our overseas procurement programs and found that they, like most other China-based suppliers, repointed their drill bits in-house. After repointing, they inspect the cutting face of each drill bit under a stereo zoom microscope. While this is a fine tool for inspecting larger diameters, I had a hunch that it wasn't ideal for the microvia drill bits that I saw them repointing at the time. I made a comment to the quality engineer and the GM that I bet they never reject bits after the first time repointing. They were very proud to say that I was correct. Their quality of repointing was so good that they never found rejections and rarely a need for reworking. I proceeded to pull out a box of freshly repointed drill bits and inspect them hard under the scope. On the third one I found a large gouge in the cutting face of the drill bit. Gouges like this are a primary root cause for hole-wall roughness.

This affirmed my theory in that the largest challenge in manually repointing isn't the repointing process itself. The challenge lies in actually seeing the drill bit for inspection after repointing.

Thankfully, advances in PCB equipment technology have a direct answer for this challenge. We found suppliers that have integrated incoming and outgoing automated optical inspection units for drill bits. Combined with an automated, vision-aided repointing unit, this makes for a near bulletproof repointing process that meets the goal of having repointed drill bits equal in quality and geometry to brand new bits. Whether this function is performed in-house or outsourced, it's critical to ensure that it's being done in the best manner

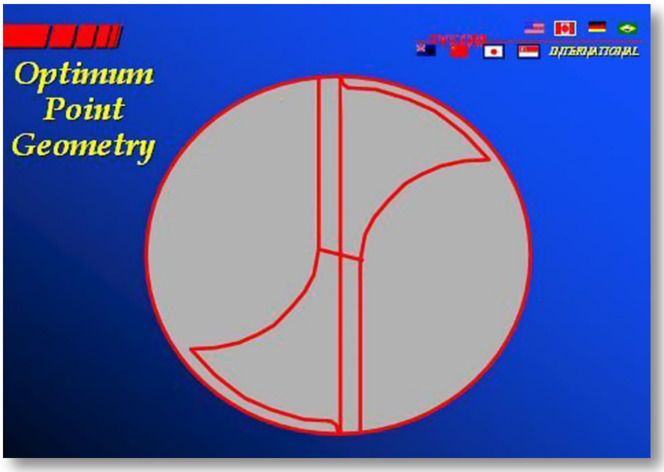


Figure 5: AOI 1.

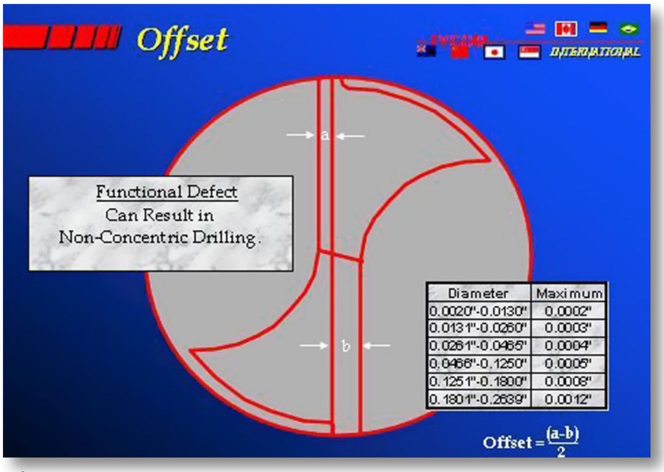


Figure 6: AOI 2.

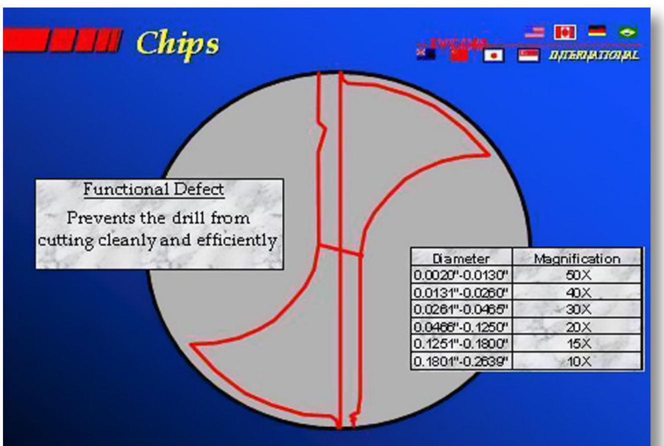


Figure 7: AOI 3.

possible. Below are just some of the items that AOI inspection looks for. A full report can be found here, courtesy of our partners Kyocera Tycom.

Drilling Parameters and Controls

In our industry folks love to talk about higher spindle speeds and the latest machines with all the bells and whistles, as if these alone control drill-hole quality. I would argue, in fact, that this is the last thing one should look at when determining optimum drill wall quality.

Most paramount are the actual parameters used:

1. Chipload—a function of speed (RPM) and feed rate into the material
2. Retract rate—how quickly the drill bit is removed from the material
3. Hit count—maximum number of holes that can be drilled with a single drill bit before it is retired and replaced by a new bit

The factors vary for given diameters depending upon, but not limited to, the following product characteristics:

1. Material type
2. Layer count
3. Thickness
4. Total copper weight

The first step is determining what the proper characteristics are. A good place (but not final place) is to obtain the recommended drilling parameters from the drill bit manufacturer. You will find these recommendations to differ from one manufacturer to the other. This is the key reason why we sole-source drill bits in lieu of having a system to appropriate the proper feed and speeds to particular drill bits.

Once these baseline parameters are in hand, it is essential to test them out by drilling test vehicles and then cross-sectioning first, last, and incremental hit counts. The desirable results will be that the you have proper hole wall on the first hit, and the hole wall on the last hit is indiscernible from this. Adjusting chipload or reducing hit count is the optimum approach to achieving desired hole quality. The next step is ensuring that these parameters are properly used.

Regardless of the method used, they can be fully effective if the right level of controls and

Method	Pros	Cons
Drill Operator inputs based on part characteristics	Gives operator ownership of process	Ripe for potential of operator error; Requires extremely robust training and systems to inform operator of driving characteristics
CAM Operator inputs parameters into header of drill program	Centralizes drill parameters; Concentrates responsibility to fewer operators; Removes drill operator from decision making process	System-wide changes to parameters need to be manually input to older part programs (potential to miss, increased resources required)
System software assigns parameters based on protocols established	Centralizes drill parameters; Allows for system-wide updates; Allows for multi-input algorithms	High up-front cost; IT requirements

Figure 8: Pros and cons of methods in practice.

checks are in place. It is imperative that PCB users include this in supplier audits.

Copper Plating Quality

Once proper lamination and drilling parameters have been established and verified to be optimal, the work continues. In order to pass military and automotive reliability testing, the PCB must pass thermal cycling and thermal shock testing. Having an automotive history, we rely on daisy chain coupons and measure

Figure 9: Plating line.

to ensure less than a 10% change in resistance after 1000-hour thermal cycling between various endpoints.

Not only does this test lamination and drilling quality, but it also tests the tensile strength and elongation properties of the copper plating itself. Good tensile strength and elongation properties combined with sufficient copper plating thickness will yield better results in a thermal cycling environment.

As such, this brings about two primary challenges in copper plating:

1. How do I achieve high tensile strength and elongation properties?
2. How do I control my plating parameters to ensure I meet a set minimum thickness and control variation to ensure that there are no low plating thickness areas?

Tensile Strength and Elongation

The first step in enhancing these PCB plating characteristics is choice of chemistry. The PCB fabrication industry's illustrious history has resulted a multitude of plating chemistry choices (even from within the same supplier). Attempting to widen the process window, some chemistries promote the ease-of-use selling point; as a result, a frequent (and major) drawback is lower thermal performance.

Aside from copper sulfate, the primary components of a copper plating bath are the car-

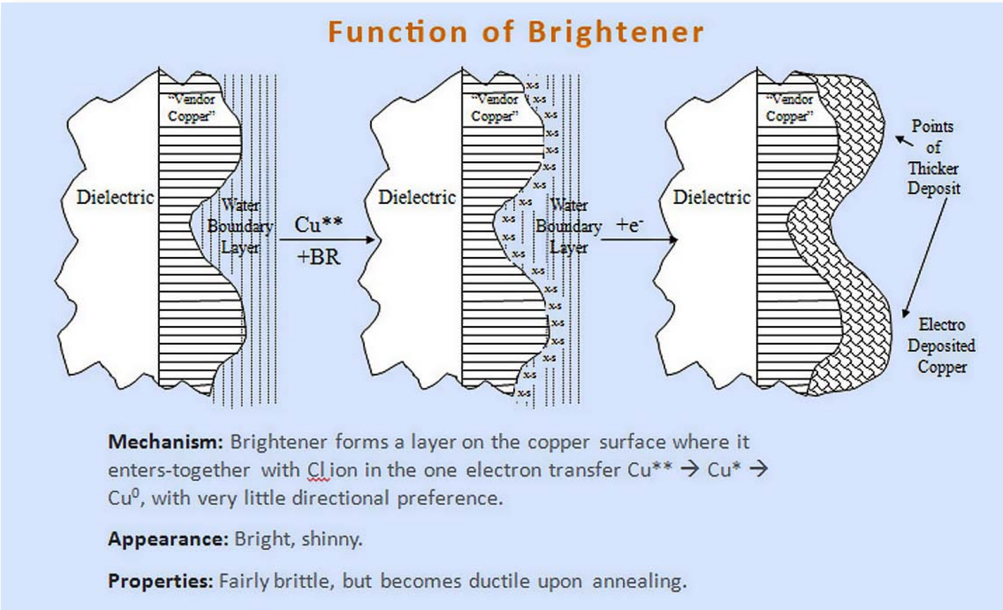


Figure 10: Function of brightener.

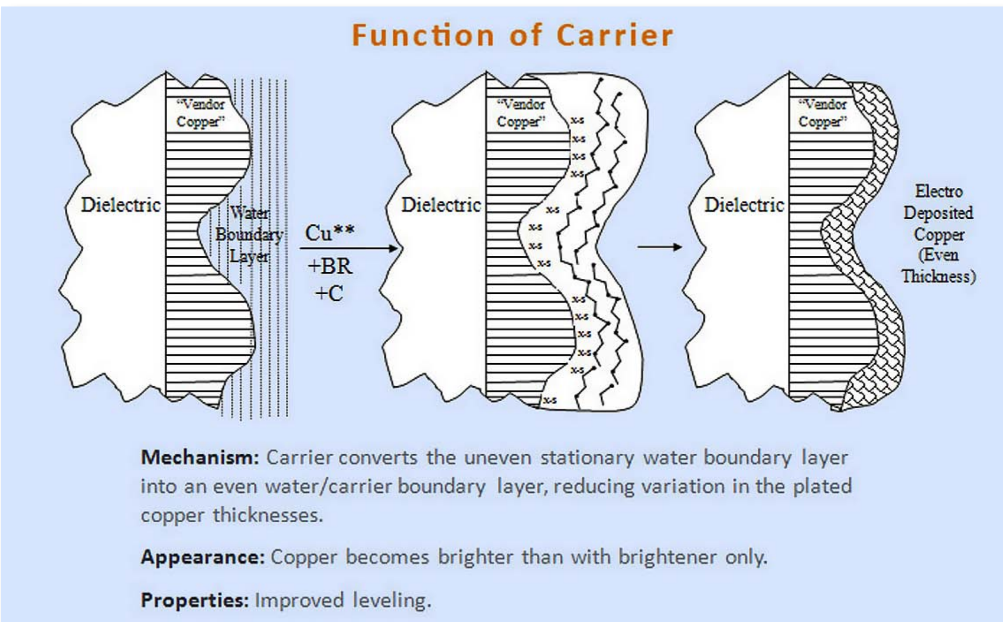


Figure 11: Function of carrier.

rier and brightener. Keeping these in proper concentration yields fine grain equiaxial plating structure (fine grain structure) that has high tensile strength and elongation properties.

Carrier has two primary functions:

1. Suppress plating to avoid high thickness at knee of the hole
2. Support brightener

Brightener functions as the grain refiner; it is the primary contributor to achieving fine grain structure copper plating.

Of key importance to keeping these components in balance is frequent testing. Testing is performed through either Hull Cell or CVS. Hull Cell testing is perfectly acceptable for DC copper plating due to the wide process window associated with this process. However, it will not function for reverse pulse plating baths since it does not discretely test for carrier. The CVS testing method is a requirement for reverse pulse plating baths. It also makes DC plating testing more exact. Below is a chart of possible bath conditions and associated failure modes.

Possible Bath Conditions

Copper Plating Effectiveness and Variation Control

Many folks associate effective and repeatable copper plating with large, automated plating lines and just the opposite with small, manually operated plating lines. I would argue that this is akin to looking at your watch to check the temperature. Copper plating thickness is merely a function of amps and time in bath. Simply put, the higher the amps the lower the time required to achieve a set plating thickness. Technically speaking, the

Test Condition	Associated Failure Mode
Low concentration	Results in burned, dull looking deposit. This is not fine grain structure copper plating and is likely to fracture during thermal cycling.
High concentration	Results in higher organic content in bath. This promotes columnar copper plating. This type of copper plating has a larger grain, often associated with poor performance in thermal cycling.
High Organic Footprint	Organic content is introduced to the batch from developers, cleaners, pigmentation, etc. that are used in materials and previous processes. This will also result in columnar copper plating structure that is associated with low thermal cycling performance. Need strict carbon treating schedule to stay within specification and keep low organic footprint.

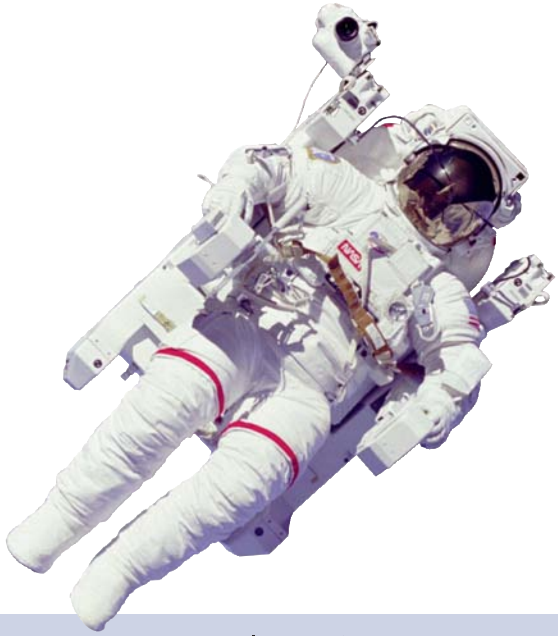
Figure 12: Test conditions.

Action	Effect
Plate panels one-high in the plating rack	Reduced variation via smaller anode area
28" Anode-to-anode distance	This is the optimal distance to insure that the production panel area is adequately covered by anode area, without being so far as to reduce the effectiveness of the anodes
Water-submerged cathodes	Eliminates possibility of reduced contact due to oxidation of mating metal areas
Chemical-submerged anode bars	Eliminates possibility of reduced contact due to oxidation of mating metal areas
Mechanical agitation	Promotes chemistry flow through holes
Vibration	Helps to remove air from microvias and blind microvias
Dual-sided rectification	Delivers optimal amperage to each side of the production panel
Advanced rectification	Newer DC and reverse pulse rectifiers have more consistent energy flow
Reduced Amps per Square Foot (11-15 for DC plating)	Plating at reduced ASF for longer cycle time reduces plating variation

Figure 13: PCB fabricator's combative steps.

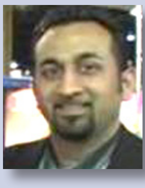
higher the amps, typically the higher the thickness variation across a production panel. High variation increases the likelihood of having insufficient plating thickness in the hole.

The three aforementioned processes feed directly into each other. Success at one process breeds success at subsequent processes. Conversely, failure at a feeder process can accelerate failure at another. For example, poor lamination sequence can result in rough hole-wall quality. Rough hole-wall quality will provide turbulence during the copper plating process, resulting in insufficient plating thickness. One bad step here ensures a domino effect in subsequent processes.



Conclusion

Unfortunately, achieving high-reliability PCB fabrication methods isn't a one word or one process answer; rather, it requires dialing in key points of the fabrication system to have optimal effects on the product. Depending upon your starting point, this program can take anywhere from a few weeks to multiple months to complete. In the end, though, it makes it easier to sleep at night knowing that products are functioning in the field to a higher degree of reliability, regardless of the application. **PCB**



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VIDEO INTERVIEW

Automated Probe Testing in High-mix PCB Fabrication

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Klaus Koziol, atg L&M director of sales North America, explains to Technical Editor Pete Starkey how a high-mix PCB shop can benefit from automating the probe-testing operation and experience the lights-out capability.

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