# Drilling of Printed Circuit Boards: An Innovative, Engineered Entry Material for Improving Accuracy of Micro and Small Diameter Drills

Rocky Hilburn, Paul St. John, Joe Bevan
Laminate Company of America,
20322 Windrow Drive, Lake Forest, CA 92630

**Abstract**
The interaction of the drill entry material and the drill tool are critical to producing accurately aligned connections between the different layers in a printed circuit board. The trend towards miniaturization and increased complexity of printed circuits requires the use of micro and small diameter (< 0.3mm) to produce the hole for subsequent plating and circuit interconnection. These smaller tools must endure end-load and torque stresses that cause the bit to deflect resulting in hole mis-registration and/or drill breakage.

The amount of force is dependent on composition of the printed circuit as well as the processing parameters such as chipload and spindle rate. Phenolic and solid aluminum entry materials, used for printed circuit drilling since the 1980s, do not have the properties required to consistently produce a high quality, small diameter drilled hole. An engineered entry material, specifically designed for use with small drills, has been developed and is currently in worldwide use. This engineered entry ensures drill accuracy and minimizes drill deflection. These benefits can improve hole quality and registration and will allow further circuit miniaturization without compromising circuit integrity. Additionally, drill efficiencies benefit from improved drill wear, less breakage, and increased stack heights.

In this paper, data will be presented on the accuracy of holes produced by small and micro diameter drill tools utilizing this new engineered entry material compared to solid, composite, and lubricated entry materials. Hole registration accuracy will be analyzed and statistically compared using the industry standard centroid method. Currently available entry materials will be compared and contrasted. Benefits and recommendations for best processing practices of the engineered entry material will also be discussed.

**Introduction**
The need for increased functionality with smaller form factors in electronic devices continues to drive the development of electronic systems with advanced composite materials, increased circuit density and extremely tight registration in multilayer PCBs. These requirements not only demand the reduction of the circuit width for routing but also the need for plated through hole vias with diameters commonly below 0.25mm and as small as 0.075mm.

The drill tools required to manufacture such small diameter holes, commonly called micro-drills, are precisely engineered, high performance tools. Like most high performance instruments these drills perform very well under a narrow set of operating conditions and very poorly under conditions based on standard or lower technology.

To ensure the performance optimization of these micro-drills and highest quality of the holes they produce, entry materials with advanced performance are required. The 90's technology drill entry materials, like solid aluminum or phenolic, are not the best entry pairings with micro-drill Rather, engineered entry materials, specifically designed for use with small drills should be the materials of choice. These engineered entry materials provide drill tool stabilization, act as a bushing to facilitate drill accuracy, and minimize drill deflection. The base materials are environmentally friendly, residue-free, and optimized for vacuum removal for high aspect ratio drilling.

A newly developed, advanced entry material is now available. This material is constructed with a proprietary coating on a sheet of aluminum. Using this engineered entry material as a 'best practices" for small hole drilling will not only provide these improvements but also benefits in drill efficiencies i.e. reduced drill wear, less breakage, and increased stack heights can be realized.

**Common Attributes of Entry Materials**
Entry materials used for drilling Printed Circuit Boards (PCB) are available in solid aluminum, phenolic, composite aluminum skinned and other combinations of these materials. These materials are provided in various thicknesses and are typically provided in sheet form.

In general, all these materials protect the top surface of the board, minimize entry burrs, and help center the drill point. It is important to understand the degree that each different type of entry material has on these attributes, and each attribute will be discussed more fully.

Protect the Top Surface

It is very important to protect the top surface of the panel stack during the drilling operation. When debris becomes impacted into the drill pressure foot the debris can damage the copper surface and potentially scrap the PCB. Any of the entry materials currently available to the PCB industry will provide adequate copper surface protection.

It is imperative that entry is used on all mechanically formed holes. Some PCB manufacturers will eliminate the entry materials when drilling holes smaller than 0.25mm because of drill breakage issues. This practice should be avoided because drilling without the entry material, does not allow the drill tool to center well and can result in significant drill deflection. The drill tool and entry suppliers should be consulted for recommendations if drills are breaking when using an entry material,.

Minimize Entry Burrs

Entry burrs typically result from non-intimate contact of the entry to the copper surface. These burrs can result in a scrapped PCB. Any burr that exists after drilling can potentially be “rolled” into the barrel of the hole, creating an opportunity to produce a void or blowhole in the plated through hole. Blowholes occur when liquid or air trapped in the electrodeposited copper during through hole plating is heated rapidly. This usually occurs during the thermal excursion at the wave soldering operation when the components are on the board. The larger the burr is after drill, the greater the chance of a potential problem in subsequent processing.

There are various ways of checking for entry burrs. The least effective way is by passing your fingertips over the drilled surface of the PCB. The average fingertip will only detect burrs that are greater than 15µm. There are better and more quantitative methods that are accepted throughout the industry. Scanning profilometry and cross-sectional analysis are two such methods for this analysis.

Profilometers can be contact (stylus) or non-contact (laser scan). A scanning profilometer has a high degree of sensitivity and can have vertical resolutions down to 0.25µm for stylus and .01 µm for laser scan profilometers. Analysis with a contact profilometer can be time consuming and laborious. This equipment is also expensive and not readily available to PCB manufacturers.

Cross-section analysis from the target area or coupon can provide the same resolution as the scanning profilometer. Cross sectioning capability is an essential analysis tool available at all PCB manufacturers. It is very low cost, provides quick results, and has the required accuracy. The target area should be carefully extracted from the PCB and encapsulated in acrylic or epoxy to preserve the burr. The grinding operation should be conducted in the same manner as when the hole wall is being evaluated so the burr can be correctly dimensioned.

Centering of the Drill Point

The position of the drill point upon entering the top of the panel stack affects the location of the hole at the bottom of the drilled PCB stack. The more accurate the drill is centered, the more accurate the location will be on the exit side (see Figures 1 and 2).


Figure 1 – Effects of entry location

**Hole Registration Accuracy**

Perhaps the greatest potential impact of entry material selection is to optimize hole registration accuracy. This is important because when the entry material allows the drill tool to maintain its original location and minimize deflection, the hole has the best opportunity to make a proper through hole connection and diminish the opportunity to short adjacent circuitry. This portion of the paper shows the data from a study constructed to determine the influence of the entry material on the location accuracy.

Materials tested

Four different entry materials were studied. These included materials 1, 2, and 3 listed below. The fourth material was the new advanced engineered entry material. Details of these materials are as follows:

**Variables (Different Types of Entry Materials Tested)**

- Composite Aluminum Clad Entry (material 1)
  0.30mm thick
- Solid Aluminum (material 2)
  3003 alloy – H19 Hardness
  0.18mm thick
- Lubricated Entry Sheet (material 3)
  0.31mm thick
- Engineered Entry Material (material 4)
  0.23mm thick

Accuracy Measurements

Accuracy data may be collected by several different methods. These methods may affect the results. Different lighting methods, camera resolution, quality of the optics, magnification and the software algorithms used to identify the actual edge of the hole can affect the results.

For this study the measuring equipment employed top-down lighting of the PCB. The software algorithm identified 96 points around the circumference of the hole, determined the best fit for a circle, and calculated the hole location.

Several different ways of measuring the acceptability of the accuracy are identified in the information that follows. These include CpK, TPD, TPR and Linear measurements. Each of these is a satisfactory way of determining the acceptability of the accuracy measurements and tolerances used. To reiterate, some methods are more accurate than others. Definitions of these terms are below;

- **CpK** – A statistical tool that reflects the relationship of the current process means and distribution proximity to the closest specification limit. CpK allows one to predict future performance based upon the actual data. Cpk requires the process be in control to be valid.

- **TPD** - An acronym for True Position Diameter, describing the actual diameter of the area that is occupied by the data.
- **TPR** - An acronym for True Position Radius, describing the actual diameter of the area that is occupied by the data and is exactly 0.5 of the TPD above.
- **Linear** - This describes the amount of error in the X & Y axis and would form a square on a scatter chart. This method of analyzing accuracy data is limited because the data will result in a circular pattern.

This study uses TPR and CpK as the methods of choice to evaluate the location accuracy data. The TPR and CpK methodologies were considered the best methods for determining drilled hole position and comparison of the hole accuracy of the tested materials.

<u>Test Matrix and Conditions</u>
The test matrix included a 0.35mm diameter tool on a two-high stack of 1.60mm thick 2-sided FR-4 laminate. Location accuracy measurements were taken at the top of the stack to determine the best performing material for maintaining the desired position. The observations shown in Figure 1 may be intuitively obvious i.e. the lower the amount of deviation the drill starts with on the drilled panel, the tighter the TPR of the drilled hole when measured on the bottom of the panel. Also, the drill tool cannot correct its trajectory when it starts to drill off location.

Multiple PCB panels can be drilled at the same time by one drill head and drill tool in order to maximize drill efficiencies. The number of stacked PCB's under the drill head is called a drill stack. In this study a two-high drill stack was used. The drill stack is limited by the PCBs' combined thicknesses and the flute length of the drill tool. The height of the stack cannot exceed the length of the drill flute and must allow the drill to enter the backup approximately 1x the tool diameter or a maximum of 1.0mm, whichever is less. Also, there must be enough flute length above the stack to allow for chip evacuation of a minimum of 2x the drill diameter.

The effects of stack height on drill deflection are shown in Figure 3. The True Position Radius (TPR) is shown to increase as the stack height is increased. The greater the TPR the less accurate the drilled hole.


Figure 2 – Two-high PCB Drilling Stack

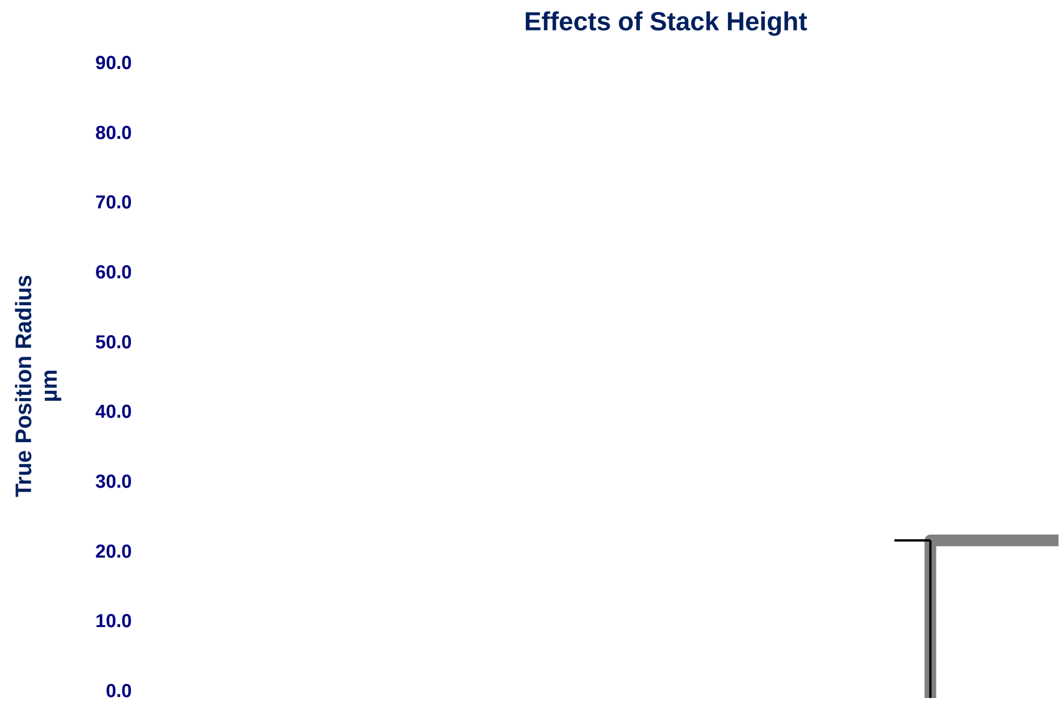


Figure 3- Effects of Stack height on drill deflection

<u>FR4 Laminate</u>

Drilling a two-high stack of 1.60mm thick double-sided (1oz. [35 µm] Cu on both sides) material provides a realistic representation of drilling in production. This test provides information on how the entry materials perform when used in typical manufacturing applications.

This method requires that the desired entry material be placed on the top of the PCB stack. The actual location of the hole position is determined from measuring the location of the drilled hole in the top of the top panel. Additional measurements can be made on the exit side of the bottom panel. This provides information about the degradation of the location through the panel stack. The exit side location information is not a part of this report.

<u>Test Conditions</u>

**Material**

- 2-layer double –sided (1.60mm thick)
  ISOLA FR4 material

**Parameters**

- Diameter: 0.35mm
  Flute Length: 5.58mm
  Drill Series: 6030
- Speed: 125,000 rpm
- Feed: 100 ipm
- Retract: 600 ipm
- Max Hits: 200 (To eliminate drill wear as a variable)
- Backup: LCOA Spectrum GOLD

**Response Variables**

- Accuracy Measurements
  Top side of the top panel (To minimize effect of material)

**Drilling Process Information**

- All panels were drilled on a single spindle machine. Same machine for all panels to minimize variation

**Accuracy Process Information**

- All accuracy measurements were obtained with an ITRAN Vision System.

- Two 1.15mm diameter holes were used to align the vision system to the drilled pattern.
- Panels were sent through a high-pressure air spray to remove any debris that may have been in the holes. Debris will negatively affect the reliability of the results obtained from a vision system.
- Panels were allowed to stabilize in the room with the Vision System for 48-hours prior to processing.

Results

Linear scatter plots showing the measured hole location for each of the materials tested are shown in Figures 4, 5, 6, and 7. The X and Y axis show the measured drill location in microns. These plots use a TPR in microns to view the accuracy of the drilled hole using the different entry materials. A 38 µm tolerance was used to determine the CpK value for all materials. All data points are referenced from the true location of the drill program.

Colored circles on these charts also represent TPR values within a maximum range. The Blue (outermost) circle and plotted point represent the limit and points within a TPR of 53.8 µm. The Green and Cyan circles represent the limits and points within a TPR of 35.6 and 17.8 µm respectively. The Red circle shows the TPR value of all the plotted points. The TPR value for the material is shown in the bottom right-hand corner of the figure.

It is readily observable from these scatter plots that the engineered entry material exhibited the tightest grouping of drill location. The engineered entry material gave a TPR of 13.5 µm and the calculated CpK was 3.9. The material's ability to center the drill accurately and act as a bushing to ensure minimal drill deflection is key to the observation. A comparison of the CpKs of the tested materials is shown in Figure 8.

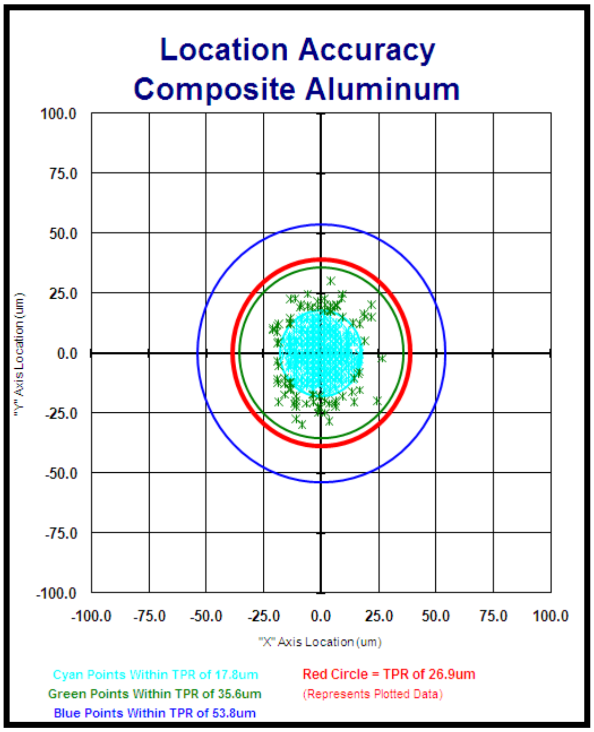


**Figure 4**

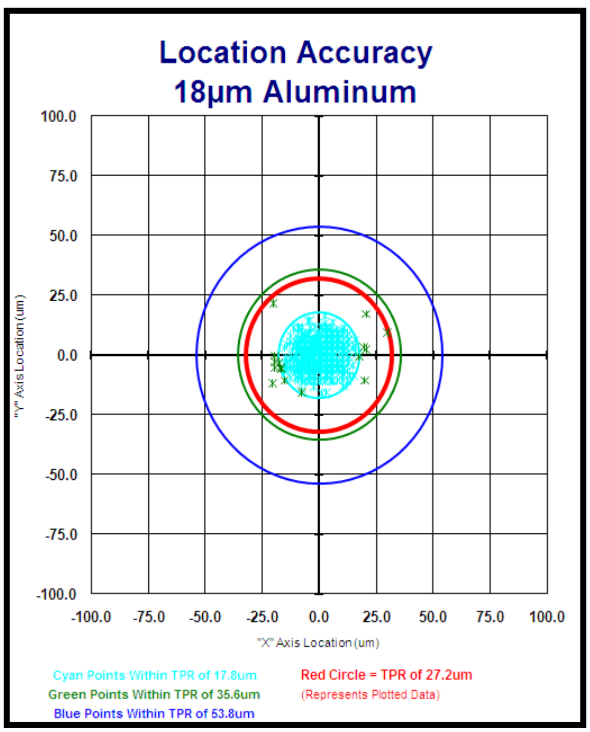


**Figure 5**

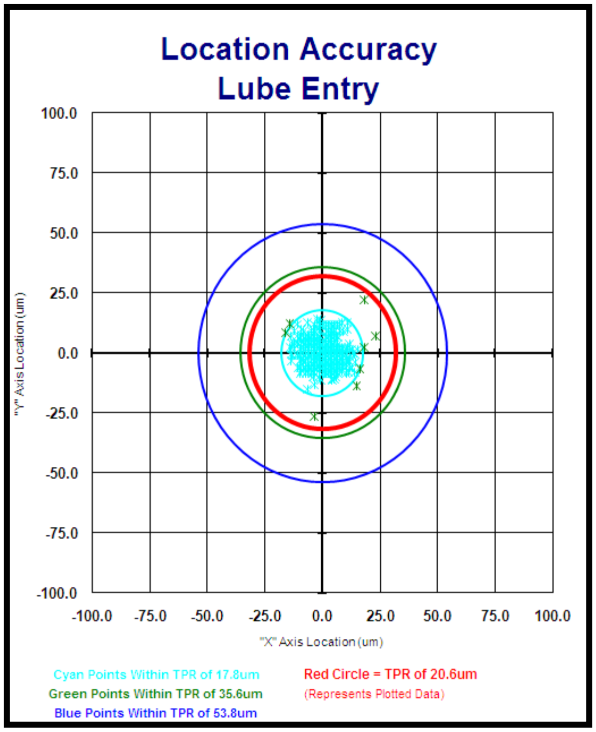


**Figure 6**

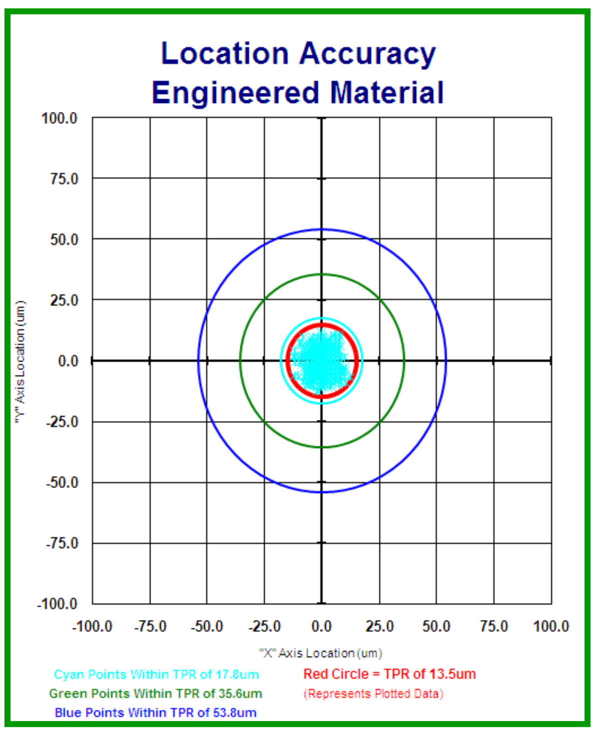


**Figure 7**

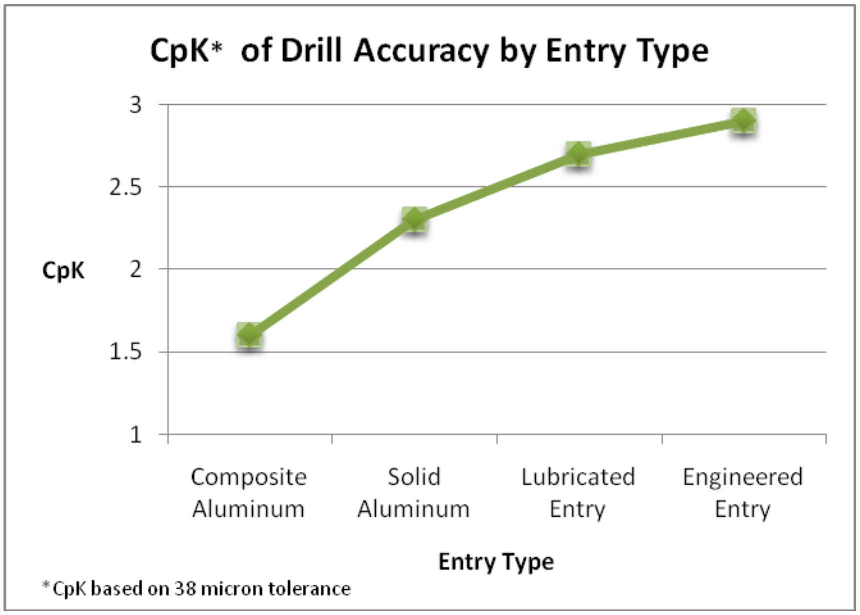


**Figure 8 -** CpK results of tested entry materials

**Other Considerations**

Drill room efficiencies and additional benefits achieved
Given the ever increasing number of holes in PCB panels and the amount of drill time required to drill each part, any advantage that can be achieved to increase efficiency without sacrifice to quality is welcomed. Some of the efficiencies and benefits observed during several field trials and results from several customers currently using the engineered entry material presented in this paper are:

- The ability to increase drill size (diameter) due to the decrease in drill deflection and maintain annular ring. This can lead to savings by reduction in drill cost and reduction in drill breakage.
- The ability to drill through high aspect ratio parts with micro-drills while maintaining registration can eliminate the need to “flip drill” or drill 50% of the hole depth, flip the panel and drill the remainder of the hole.[1] This benefit has enabled some of the users of this material to cut their drill time by 50% while maintaining accuracy.
- The ability to drill higher density, smaller drill diameters on current equipment (by an increase in accuracy) eliminating the need for new capital expenditure.
- The ability to reduce scrap due to drill deflection.
- The ability to reduce manufacturing cycle time.

[1]This is only an option if adequate flute length is available, however since accuracy is increased a larger diameter drill can sometime be used giving more available flute length.

Pairing of drill entry and back-up for critical registration requirements
As discussed above, drill room throughput efficiency is an important consideration. Given the ever increasing price pressure on the printed circuits manufacturing industry, drill efficiency, as well as quantifying and improving the attributes listed above, can reduce drilling related costs. One way to achieve a reduction in drill related costs is to pair the registration technology with a technology that allows an increase in hit count; thus maintaining the integrity and to some degree the quality of the drilled hole.

This technology incorporates a lubrication mechanism into the drill backup material. Lubricated backup provides these benefits:

- Reduces Drilling Temperatures – lubricating properties significantly lower drilling temperatures minimizing heat-related hole defects and drill wear.
- Improves Hole Quality – lubricating properties substantially reduce hole roughness and drill wear.

When the engineered entry and lubricated backup technologies are used in tandem, they can give the following benefits:

- Increase in hole wall quality.
- Increase in drill hit count by reducing wear.
- Enhancement of registration by maintaining a sharp cutting surface on the drill reducing deflection.
- Reduction in cost per hole (savings in drill cost outweighs the additional cost of materials).

**Conclusions**

Requirements for entry materials for drilling small holes were reviewed. Tests were conducted to determine the effect of different entry materials on drilled hole location accuracy. A quantifiable difference in drilled hole location accuracy can be observed when utilizing different entry materials. The recently commercialized engineered entry material consistently performs better than other available entry materials in regards to drilling of small diameter drill tools. This material shows advancement in the ability of an entry material to improve and maintain better location accuracy.

After evaluating all of the available data from the testing, we can conclude the following:

- The engineered entry provides benefits that can contribute to reducing the height of entry burrs.
- The initial objective to provide quantifiable evidence that entry materials engineered for the PCB drilling process will perform better than standard solid aluminum can be accomplished.
- The difference between these materials can enhance the process window and allow better overall results that may contribute to improved yields due to improve drill accuracy.

Since this testing was conducted, several field trials and results from several customers currently using the engineered entry material have confirmed the results of this testing. This was confirmed not only on the PCB construction used in this test, but on high aspect ratio, high layer count, performance dielectric constructions.

The engineered entry material offers additional efficiencies and benefits when paired with lubricated drill backup. Some of the benefits given were:

- The ability to increase drill size (diameter) due to the decrease in drill deflection and maintain annular ring. This can lead to savings by reduction in drill cost and reduction in drill breakage.
- The ability to reduce scrap due to drill deflection.
- The ability to reduce manufacturing cycle time.
- Increase in hole wall quality.
- Increase in drill hit count by reducing wear.

This newly developed advanced entry material is the forerunner of a next generation of drill room solutions for the increased complexity in printed circuits with the micro-drills used to manufacture the required registration accuracy.

**Author Bios**

Mr. Hilburn is the Product Development Manager for Laminating Company of America and CAC Inc. Prior to joining L.C.O.A. he was Director of Technical Marketing for Ticer Technologies and Manager of New Product Development for Gould Electronics in Chandler, AZ.

Rocky is currently responsible for developing, strategic selection and commercialization of L.C.O.A.'s new products. He has extensive experience in the electronics industry in new technology and product development at OEM and printed circuit fabrications levels.

Mr. Hilburn is a frequent speaker on both embedded resistor and capacitor implementation. He is a member of the D-37 Embedded Passive Task group and chairman of the D-15 Flexible Circuits Test Methods Subcommittee for IPC. Mr. Hilburn holds a bachelor's degree from the University of Missouri in Chemistry.

Mr. St. John is the worldwide technical manager for L.C.O.A. Prior to joining L.C.O.A. he worked in various PCB shops until 1990 before moving to Tulon Company as the Application Engineering Manager and transferring to Kyocera Tycom Company as the Southwestern Regional Technical Manager. Paul has been dedicated to working directly with PCB drill departments around the world for the past 15 years and continues to focus on improving the drill process and removing cost from the drilling process of his customers.

Paul is currently responsible for supporting L.C.O.A.'s business worldwide, introducing new products to its customer base, removing cost from their process, and improving the efficiency and yield produced in the s drill room.

Mr. Bevan is currently Sales Manager for LCOA and CAC, Inc. Prior to joining LCOA and CAC, Joe was Sales Manager for the Eastern US for Gould Electronics PCB products. Joe has worked in the Printed Circuit Industry since joining Western Electric in 1975.

Joe worked until 1992 in various capacities within the PCB industry including the Position of President of Circuit Concepts, Inc in Richmond VA. Joe was involved with the introduction and development of many new processes and presented several papers on his work to the SMTA. Since 1992 Joe has focused his efforts on sales and technical support of LCOA and CAC products in the North American PCB industry.