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MACFEST: Benchmarking a new solder-able finish for the PCB industry

by *Thomas Jones*

New, innovative manufacturing procedures have been developed by the recently completed project, **M**anufacturing **A**dvanced **C**oating for **F**uture **E**lectronics **S**ys**T**ems (MACFEST, www.macfest-project.co.uk), which has been funded by several partners and the government's Innovate UK. The objective of the project was to harness the potential of Ionic Liquid technology, to be used as a substitute for dangerous and costly processing chemistries applied in Printed Circuit Board (PCB) manufacture.

The specific process under consideration for Ionic Liquids was the **E**lectroless **N**ickel **I**mmersion **P**alladium **I**mmersion **G**old (ENIPIG), plating finish. ENIPIG is recognised as a 'universal finish' [1], as it allows a circuit designer to cater for the competing needs of wire bonding and surface mount soldering, which are often both required for high density circuit designs. The chemistries currently applied within the ENIPIG process employ the use of complex multistage processes with high material costs and with dangerous chemical formulations. These costly processing factors can be overcome by the substitution of novel Ionic Liquids, developed by the University of Leicester (UoL), within the ENIPIG process. [2, 3]

Merlin Circuit Technology has worked closely with UoL and Bob Willis, a recognised global expert in microelectronics testing and training, to benchmark the performance of the Ionic Liquid-ENIPIG coatings developed in the project. Tests were performed on the finish, where an evaluation of the solderability was made. Solderability provides a measure of the ease with which a solder joint can be made between materials and includes a review of the wetting of the solder to the board surface. Solderability is a vital parameter defining the success of component assembly onto a PCB, where poor quality could result in a manufacturing or an in service failure.

A PCB test board was provided by Bob Willis to evaluate the quality of the new Ionic Liquid-ENIPIG finish for the 2016, Swedish Electronics Exhibition (SEE) in Stockholm. As part of the testing, Bob offered to benchmark the performance of the Ionic Liquid-ENIPIG finish against existing finishes applied in industry.

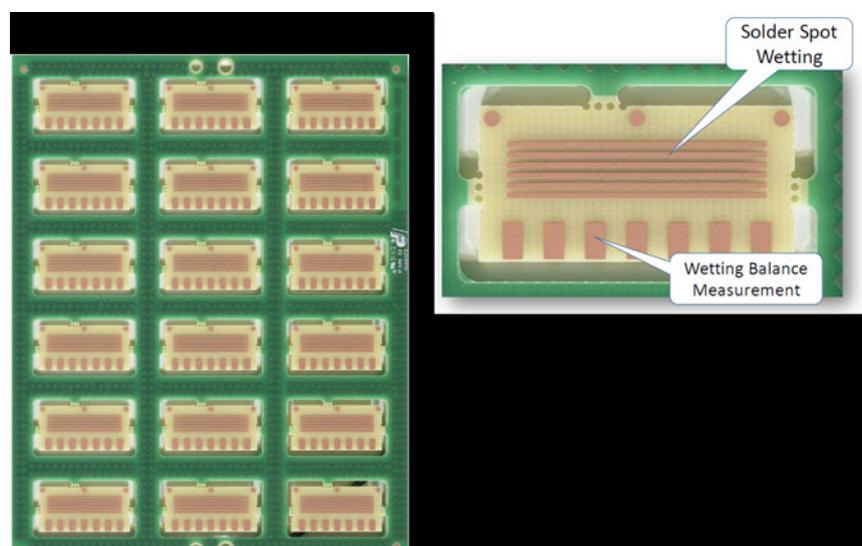


Figure 1 - Test board for solderability evaluation. 18 test coupons for solder spot and wetting balance measurements. 6 rows of tracks for spot patterning of 22 paste dots and 7 pads for wetting balance measurement

The test boards are highlighted in Figure 1, showing a 15.3 cm by 10.2 cm panel with a copper finish which includes smaller pop-out coupons. A single board contained 18 test coupons for solder spot wetting and wetting balance measurements.

The test boards were plated at the UoL with an Ionic Liquid-ENIPIG finish. The thickness of the finish was measured using an X-ray Fluorescence (XRF) device at Merlin Circuit Technology, Deeside. The plating outcome is displayed in Figure 2, showing a plot of the metal thickness measured tangential to the surface of the board for the different metals applied in the Ionic Liquid-ENIPIG and on different pad sizes. Two pads were measured. One was a 10.5 mm rectangular pad and the other was a 1.8 mm circular pad. The plating behaviour typically varied for the immersion palladium and gold plating processes, depending on the area and shape of the pad plated. The general trend showed that pads of a larger surface area produced thinner deposits. The Ionic Liquid-ENIPIG was no different, showing a variation in plated thickness dependent on the pad feature size.

When processing the panels, the amount of metal plated was deposited down to within the standard set by the IPC, and as outlined for ENIPIG plating, which stipulates Ni, 3 - 6 μm , Pd, 50 - 150 nm and Au, 25 nm or larger [4]. The measured thicknesses were within the guidelines, showing that the Ionic Liquid chemistry could be made to perform comparably to the existing processes. The Pd thickness failed to measure on the large pad due to the detection limit of the XRF device, although independent measurements, not shown, confirmed that Pd had deposited to within minimum specification.

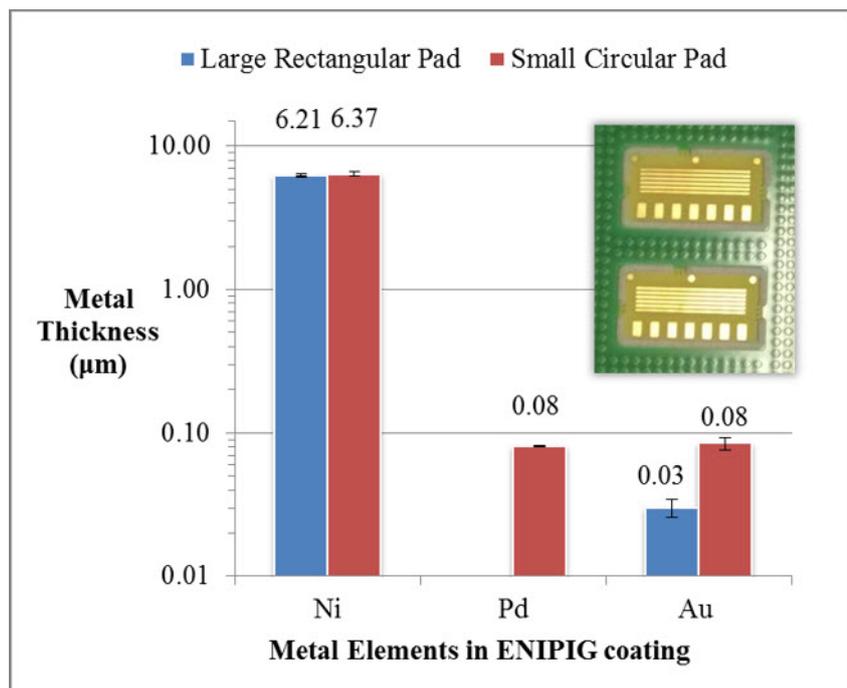


Figure 2 - X-ray fluorescence measurements obtained at Merlin Circuit Technology, of the Ionic Liquid-ENIPIG finish plated at the University of Leicester. Results show average thickness for different metals on rectangular and circular pads of sizes 10.5 mm and 1.8 mm, respectively. Insert of plated board included.

After plating, the first quality test was a solder wetting balance measurement. The solder wetting balance test evaluated the ability of solder to adhere to the test panel, as it was vertically submerged with flux on its surface into a bath of molten solder. Once submerged, the solder climbed up the panel and the quality of the soldering was evaluated from the total increase in weight of solder adhered onto the board and its wetting speed. [5]

Solder wetting was performed on the test coupon, as highlighted in Figure 1, where the sample was lowered into a bath and

the rectangular pads took up solder. The process is outlined in Figure 3, showing a plot of the weight of solder, measured as force against time, which is officially known as a wetting curve.

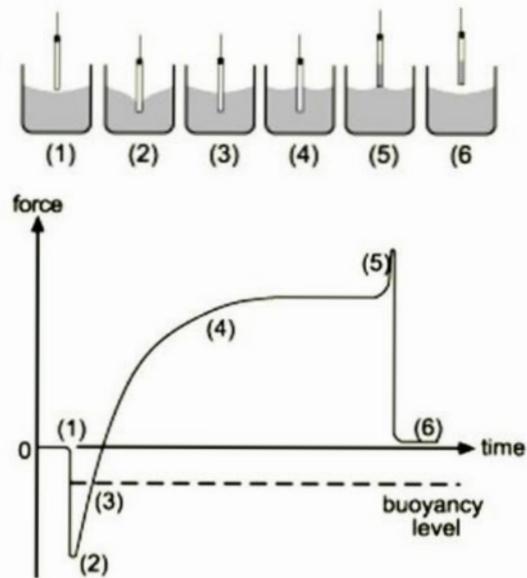


Figure 3 - Solder wetting balance test with plot of adhered solder weight force against time on a wetting curve.

The tests were benchmarked against a variety of other widely used surface finishes including Organic Solderability Preservative (OSP), Electroless Nickel Immersion Gold (ENIG), Immersion tin and Hot-Air Solder Levelled (HASL). The different finishes are applied in PCB manufacture due to the differing costs of materials and the conditions they will be expected to perform under, for example, use in the defence, aerospace, or space industries etc.

Two test boards were pre-treated before soldering. This was to mimic the conditions which the boards would undergo if they were processed in component assembly. A board may require several solder cycles dependent on the complexity of the component assembly, such as when components are added to both sides of the PCB. This will occur in two separate process heating operations. One such process could involve: the pre-treatment of the surface by a flux solution, the application of solder paste to the conductive pads, the application of the components to the paste covered pads and, finally, heating of the board to a temperature beyond the melting point of the solder, to enable the solder paste to reflow onto the pads, whilst aligning the components into the correct positions on the pads. If the board requires further component assembly then the pads on the unprocessed side of the board will have degraded in surface quality, due to thermal expansions caused by the first heating operation. Therefore, it was useful to test the condition of the test boards after a heating operation to evaluate changes in quality.

Different commonly applied heating methods are convection reflow, which in these trials applied 200 mg, Sn-Ag-Cu (SAC) lead free solder alloy at peak temperatures of 260 °C and vapour phase reflow, which applied Galden (an inert high boiling inert heat transfer fluid) at peak temperatures of 240 °C. Vapour phase soldering typically induces a more uniform distribution of heat to the board by the process of latent heat of condensation, enabling a more uniform solder quality of the different components. It also provides a reduced operational costs and risk from fires, due to the more safe heating method and so for these reasons is often used in manufacture [6].

Highlighted in Figure 4 is a plot of the average force of the wetted solder weight after two seconds immersion for the different finishes and pre-treatments. The Ionic Liquid-ENIPIG results showed that the amount of solder wetted varied little between the different processing conditions and that the temperature ageing of the board induced only small performance changes. The finish performed on par with existing industry finishes such as ENIG.

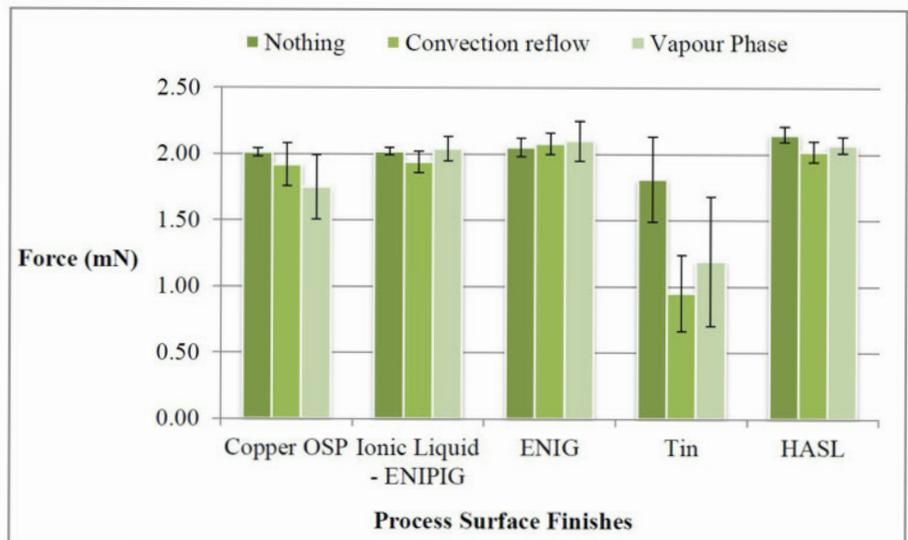


Fig. 4 - Average solder wetted weight after two seconds immersion. Test performed on five different finishes with each pre-processed under three different conditions.

Fig. 5 shows a plot of the average solder wetting time taken to reach 2/3 of the final wetting force. This shows how fast the solder wetted to the surface, where a short time is desired. The Ionic Liquid-ENIPIG showed a range of behaviours which differed depending on the pre-treatment conditions. Its performance dropped – shown by the increase in time to wet - for the application of convection reflow. Convection reflow is processed at higher peak temperatures than vapour reflow and so the impact of thermal expansion on topography, and thus solder-ability, would have been greater. Regardless, the performance drop was not significant and the time to wet was less than the majority of the other surface finishes. This showed that the surface topography of the deposit was of a sufficient quality to enable wetting to the board and displayed a high surface energy like the other surface finishes, despite heating damaging its surface.

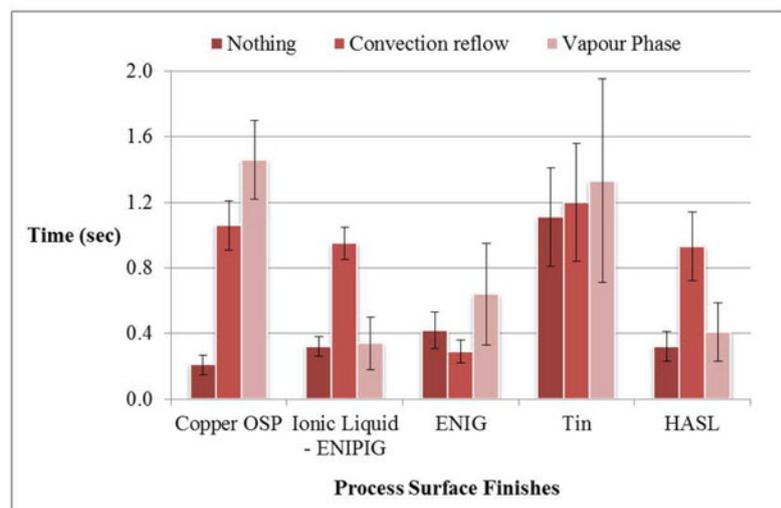


Figure 5 - Average Solder wetting time taken to reach 2/3 of the final wetting force. Test performed on five different finishes with each pre-processed under three different conditions.

The final evaluation of the solderability was the Wetting Dot Test. This evaluated the ability for solder paste to flow across test pads plated with a surface finish [7]. The test was performed using the test coupon highlighted in Figure 1 again. 22 solder paste dots were stencil printed onto the 6 tracks above the rectangular tracks, with an example shown in Figure 6. The board was then subjected to reflow heating which melted the solder paste. Upon melting, the paste spread across the surface of the pad and coalesced when it came into contact with dots. After a heating cycle the number of spots remaining on the board surface was counted, two or more coalesced spots were counted as one.

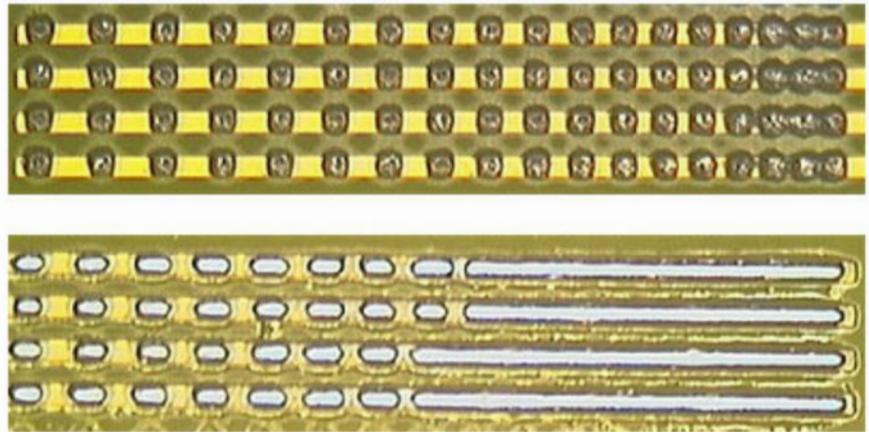


Fig. 6 - Example of solder spot test. Top shows solder spots added to tracks with reducing distance between features. Bottom shows coalesced spots after reflow heating of board.

A surface finish with high wettability allows for increased coalescence and a smaller number of counted solder spots on the surface after reflow heating. The results for the spot test are displayed in Figure 7, showing the number of spots counted for HASL, ENIG, Ionic Liquid-ENIPIG, Immersion tin and OSP. The test was performed with different pre-treatment conditions, which were convection, vapour phase, no pre-processing, and the application of nitrogen, which is used to aid soldering and to prevent surface modification [8].

When populating both sides of a PCB with components and applying two heating operations, an unintentional pause may be introduced in the manufacturing process between heating cycles, due to the work load of the assemblers. During this pause in processing oxidation occurs on the metal surface, negatively influencing the performance of the board for soldering [9]. For this reason, an additional test was performed whereby convection and vapour phase reflow operation were performed individually on test boards, and a hold period introduced - to simulate degradation which may occur when leaving the boards during component assembly - before spot wetting testing.

The results showed that the most effective finish for coalescence of spots was the HASL, and the least effective was the OSP, which were unsurprising results. The performance of the finishes dropped with the introduction of a hold cycle and for processing at higher temperatures - such as processing under convection reflow - which was also as expected. The Ionic Liquid - ENIPIG performed well relative to the other finishes, where coalescence was high on its surface regardless of the pre-treatment conditions. The finish specifically performed better than the ENIG, which had a similar material composition and topography.

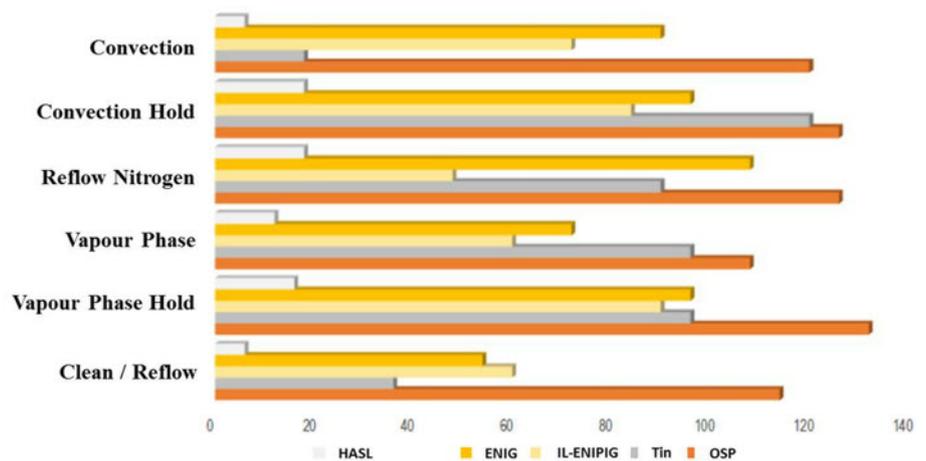


Fig. 7 - Solder spot wetting test results for different plated finishes and processing conditions.

Conclusions and Future Studies

The performance of the new Ionic Liquid – ENIPIG finish was benchmarked against widely applied surface finishes for the PCB industry, where its performance was exemplary in terms of the solder-ability.

One of the uses of the ENIPIG finish is for high density circuit builds with small feature sizes. To connect the PCB to the small pad features on the integrated circuit component, wire bonding is required. Trials are being developed for the remainder of the project, looking to test the ability to wire bond to the surface finish, defining its bond strength and performance on differing pad sizes.

To date, Ionic Liquids have performed well in their bespoke applications within PCB manufacture. The success to date of the **MACFEST project and the potential for cost savings from the novel chemical formulation** shows that their continued development and introduction into manufacturing is well worth pursuing.

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