Electrostatic Discharge Properties in Resin 3D Printing

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Abstract

There is a need for manufacturers of circuit boards to rapidly and affordably create jigs and fixtures with Electrostatic Discharge (ESD) properties compared to current methods. Loctite® 3D IND3380 is a 3D printable resin that can be used to create physical parts with ESD properties and without the need for machining or molding. ESD properties are achieved with a variety of printers and post-processing methods and are stable through accelerated ageing, making it a useful solution to produce ESD tooling enabling the production of modern electronics.

Background

The manufacture of printed circuit boards (PCBs) with integrated circuits is a worldwide industry with an economic impact of approximately $75 billion USD worldwide[1]. The production of these circuit boards is carried out in precise and highly controlled environments designed to reduce or eliminate the possibility of creating electrical arcs – also known as Electrostatic Discharges (ESD). When these electrical arcs occur, they can damage the sensitive chips, resulting in increased rework or scrap rates. Estimates for the value of product lost due to ESD related failures range from 8-33%[2]. To greatly reduce the risk of electric arcing, items used in the manufacture of sensitive electronics are developed to have ESD properties. ESD serves as a middle ground between electrically conductive and insulative. Conductive materials will dissipate charge rapidly which can damage product, while insulative materials hang on to built-up charge until it reaches critical levels and arcs. ESD provides a middle ground where electric charge is slowly but consistently dissipated to ground, preventing electric arcs. The international norm DIN EN61340-2-3 (Methods of test for determining the resistance and resistivity of solid materials used to avoid electrostatic charge accumulation), describes a material as having ESD properties if the surface resistivity is between $10^4\ \Omega$ to $10^{11}\ \Omega$. Surface resistivity is critical as the charge builds up on and discharges from the surface of the material.

Additive Manufacturing (AM), also known as 3D Printing, is a manufacturing method that enables a user to transition rapidly from a digital design to a physical part. Once the build file is sent to the printer, the printer manufactures the geometry autonomously with minimal to no input from the operator. Because of this speed and usability, AM is used for low-to-mid volume production runs, prototyping, and the production of part-specific manufacturing aids to support more traditional manufacturing lines. These manufacturing aids, such as jigs and fixtures, that have traditionally been manufactured via machining or molding, can take weeks or even months of lead time and can be costly, especially when a full set of fixtures is needed for a product line with different sizes. But with AM, these can be produced and rapidly iterated to support a manufacturing line from pilot to scale-up to full manufacture, and to support a mature manufacturing line with replacement parts to prevent downtime. The use of ESD materials in the AM space means these manufacturing aids can be produced quicker and more economically than before.

The most known AM technology is Fused Deposition Modeling (FDM), also known as Fused Filament Fabrication (FFF). It uses thermoplastic filament extruded into the final part geometry, in which ESD products are available for use with this technology. However, there are limitations with FDM, particularly around print speed for large volume builds, surface finish, and temperature resistance. An alternative AM technology is known as Digital Light Processing (DLP), which is also known as Liquid Crystal Display (LCD), Masked Stereolithography (mSLA), or even simply resin 3D printing. In this technology, a UV reactive resin has a cross-sectional image of the desired part geometry projected onto the resin. Where the UV light hits, the resin polymerizes into a solid form. This process is repeated over and over, usually at cross-sections every 50 to 100 microns, creating a solid form slice-by-slice. Since the slice layers are small, the surface finish is very good, and allows to produce organic shapes with minimal layer lines. And as the entire slice is projected at one time, the time to produce a single layer is quite short, speeding-up the production of large parts or builds with many small parts. Lastly, as photopolymer technology creates a thermoset as opposed to a thermoplastic, different material properties can be developed, such as increased temperature resistance.

AM is a manufacturing process, and just like any process, the final output can vary based on several different variables. The workflow for resin 3D printing has the

following process steps: printing, washing of excess resin, UV post-cure, and sometimes heat cure. UV post-curing is necessary to drive the polymerization reaction to completion and achieve final properties by using a higher intensity UV light than what is found in the printer. For some combinations of materials and printers, an additional heat cure is necessary to achieve final properties. Variations in these process steps can lead to differing end properties.

Henkel's Loctite® 3D Printing develops open-platform resins for DLP/ LCD/mSLA style 3D printers with a focus on functional properties for end-use applications. Included in Loctite's 3D resin portfolio is Loctite® 3D IND3380, an ESD capable resin developed with an HDT of 190°C[3] for applications in manufacturing of circuit boards and electronic products. Consistent ESD properties are critical for the end-user, so Loctite® 3D IND3380 was developed to deliver consistent performance with a variety of printing processes and geometries.

Experimental Setup

The experiments in this study look at several different variables in the printing process, including style of printer, effect of heat curing during post-processing, and the effect of exposure time during printing. The primary output considered for ESD properties was surface resistivity.

For all the experiments, Loctite® 3D IND3380 is used as the printed material. As a variety of printers and post-cure units were used, details on each are presented in Tables 1 and 2. Printer irradiance was measured with an OAI 308 UV light meter with either 380 nm or 400 nm probes, depending on the wavelength of the printer. Isopropyl alcohol (IPA) was used to wash excess resin from parts after printing. Surface resistivity was measured with a Wolfgang Warmbier SRM 200 and Model 410 mini probe or a Wolfgang Warmbier Metriso 3000 and Model 844 mini probe. Heat curing was performed in a Memmert UF 30 Plus programmable oven.

Table 1: Printers used and key specifications.

Printer	Wavelength (nm)	Intensity (mW/cm^2)	Functionality
Stratasys Origin One	385	5	LED Projector-based light source
Nexa3D XiP Desktop	405	3	LED array with LCD mask
Carbon M2	385	5.3	Projector combined with oxygen inhibition resin membrane

Table 2: UV post-cure units and key specifications.

UV post-cure unit	Light source	Intensity (mW/cm^2)
Loctite® CL36	405 nm LED	80
Dymax 5000-EC	Metal halide bulb	150
Nexa3D Desktop Cure	405/385/365 nm LED	110

ESD properties were measured with one of two geometries as pictured in Figure 1. These were designed for testing purposes to ensure that properties can be consistently achieved for a variety of geometric conditions that printers have found traditionally challenging. An example of a measurement being performed in Figure 2.

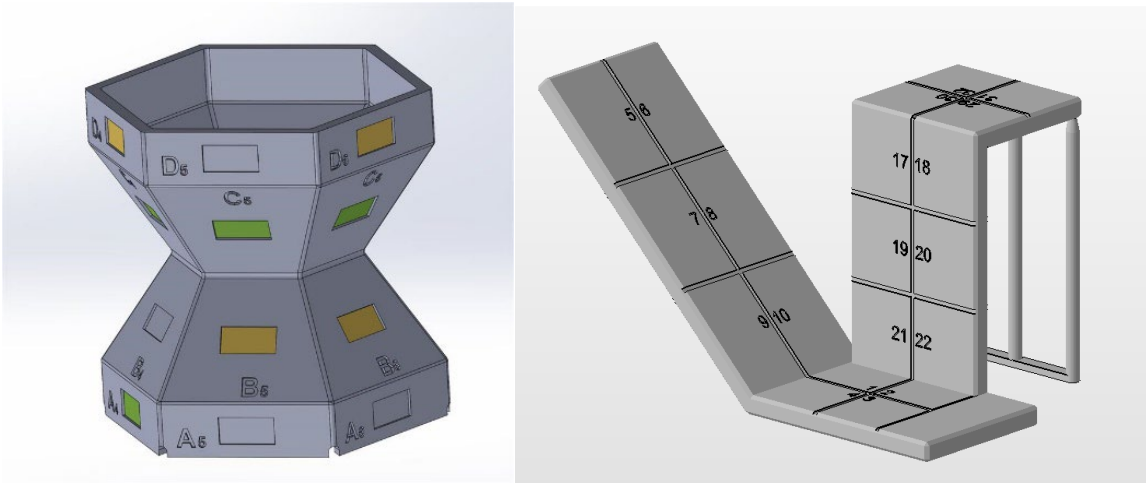

Figure 1: ESD measurement geometries. Pictured on the left is the "hourglass" geometry, while on the right is the "kickstand" geometry. Both have defined measurement areas for consistent measurement across multiple parts. The hourglass geometry is 60 mm high and 54 mm across. The kickstand geometry is 42 mm high and 44 mm wide and 74 mm long.

Figure 2: Surface resistivity being measured on an "hourglass" geometry.

Experiments and Results

Experiment #1: Effect of different printer and post-processing combinations on surface resistivity.

Loctite® 3D IND3380 samples were printed and processed via a variety of workflows as described in Table 3 using internally optimized build styles and cure times. UV post-cure measurements were performed after the UV post-cure while heat cured parts were measured after the subsequent heat treatment. Results are in table 4.

Table 3: Workflows used to create samples.

Printer	Wash	UV post-cure	Heat cure
Stratasys Origin One	2 min + 2 min IPA	Loctite® CL36, 30 min + 30 min	170°C for 3 h
Nexa3D XiP Desktop	2 min Nexa xClean + 2 min IPA	Nexa Desktop Cure, 10 min + 10 min	130°C for 1.5 h
Carbon M2	2 min IPA	Dymax 5000-EC, 10 min + 10 min	170°C for 3 h

Table 4: Measurement results from different workflows.[4,5,6]

Surface Resistivity (Ω), Geometric Mean		
Printer	UV post-cured	Heat cured
Stratasys Origin	1.42×10^6	6.33×10^5
Carbon M2	8.11×10^7	1.87×10^8
Nexa XiP	1.25×10^7	6.23×10^6

As shown by the data, all workflows achieved final surface resistivity in the range 10^5 Ω to 10^8 Ω which is in the range of 10^4 Ω to 10^{11} Ω necessary to achieve ESD properties accordingly to DIN EN 61340-2-3. This shows that ESD properties can be achieved across a range of printers and workflows with a variety of curing wavelengths. After a heat cycle, the surface resistivity of all parts remained within ESD range. Heat can be used in a workflow to increase the HDT of a printed part if temperature resistance is required.

Experiment #2: Effect of different printer exposure times on surface resistivity.

The printing process of UV curable resins effectively turns each 3D printer into a miniature chemical reactor for polymerization. Changes in the printing process parameters can result in changes to the final product. Printers project UV light at a set intensity into a vat of resin, which initiates the polymerization reaction. But polymerization is not instant, so the image is projected over the course of several seconds, usually called the exposure time. Resins usually need a specific amount of energy to cure a layer, so changing the exposure time or irradiance can lead to differences in polymerized product. As the irradiance for a given printer is normally fixed, exposure time is the main variable that can be adjusted that can affect polymerization in the printer. Exposing the resin for too short or too long of an exposure time can lead to incomplete polymerization or build failures.

Internally developed print settings on the Stratasys Origin for Loctite® 3D IND3380 have a nominal exposure time of 7 seconds at 5 mW/cm^2. To test the sensitivity of the resin, hourglass samples were printed at exposure times of 4, 7 and 10 seconds. Parts were washed in IPA, UV post-cured in a Loctite® CL36 for 30 minutes a side,

and heat cured for 3 hours at 170°C. Parts that have been washed but not yet UV post-cured are labeled as "green". Surface resistivity values are in table 5.

Table 5: Measurement results from different exposure times.[7]

Surface Resistivity (Ω), Geometric Mean			
Exposure time (s)	Green	UV post-cured	Heat cured
4	8.21×10^7	1.76×10^6	1.39×10^6
7	7.47×10^7	1.42×10^6	6.33×10^5
10	7.71×10^8	8.11×10^6	4.88×10^6

All samples were able to achieve properties within the ESD range after post-processing. While even the "green" parts were within ESD range, these parts have not fully polymerized and should not be put into service until fully post-processed to a stable final product.

Experiment #3: Effect of different z-heights on the surface resistivity of hourglass shaped sample.

Many 3D printing processes are geometry dependent. Printing unsupported overhangs or tall parts can result in parts in inaccurate geometry, inter-layer adhesion issues, or a variety of other print failures. To investigate how geometry and print height might affect surface resistivity, samples with the "hourglass" geometry were printed on a Stratasys Origin with a nominal 7 second exposure time, washed in IPA, UV post-cured in Loctite CL36, and heat cured at 170°C for 3 hours. Measurements were taken at levels "A" to "D", visible in Figure 3, with level "A" closest to the build plate. Four parts were produced, and six measurements were taken at each level on a part. The resulting surface resistivity measurements are shown in table 6.

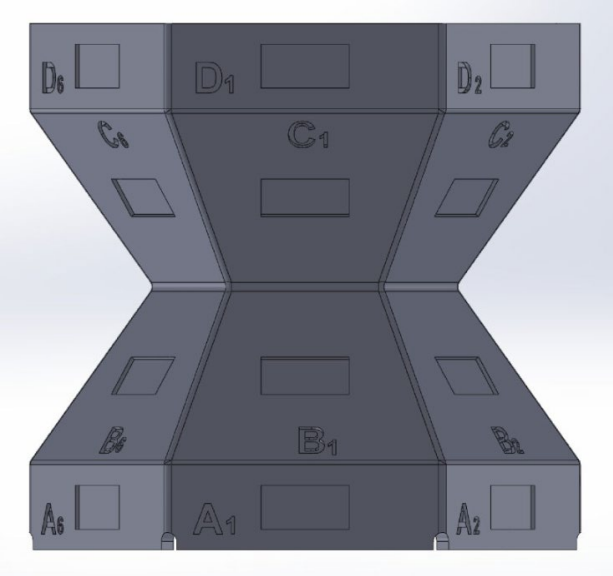

Figure 3: Z-heights used for measurement points on the hourglass model.

Table 6: Measurement results from z-heights.[7]

Surface Resistivity (Ω), Geometric Mean			
Measurement level	Green	UV post-cured	Heat cured
A	7.54×10^7	1.48×10^6	5.37×10^5
B	1.03×10^8	1.84×10^6	9.59×10^5
C	1.41×10^8	1.48×10^6	7.30×10^5
D	3.29×10^7	1.01×10^6	4.28×10^5

All levels and orientation showed surface resistivities within ESD range of 10^4 Ω to 10^{11} Ω necessary to achieve ESD properties accordingly to DIN EN 61340-2-3. It is important to note that initial base layers, which are not measured in this study, may not have ESD properties. This may be due to the drastically increased exposure time need for baseplate adhesion. A sacrificial raft may be used to ensure the entire part

has ESD properties. More details can be found on the Technical Data Sheet for Loctite® 3D IND3380 TDS.

Experiment #4: Effect of heat ageing on surface resistivity.

All properties presented so far have been measured shortly after the printing process, but polymers can age and change over time. To investigate how ESD properties may change, an hourglass sample was printed on a Stratasys Origin, washed in IPA, UV post-cured in a Dymax 5000-EC, and heat cured at 170°C for 3 hours. After cooling to room temperature, the sample was placed in a 50°C chamber for 6 weeks. Based on temperature dependence of reaction rates with the Arrhenius equation, a test time of 6 weeks at 50°C can be interpreted as approximately 12 months at ambient temperature. Surface resistivity was measured at every week and is presented in Figure 4.

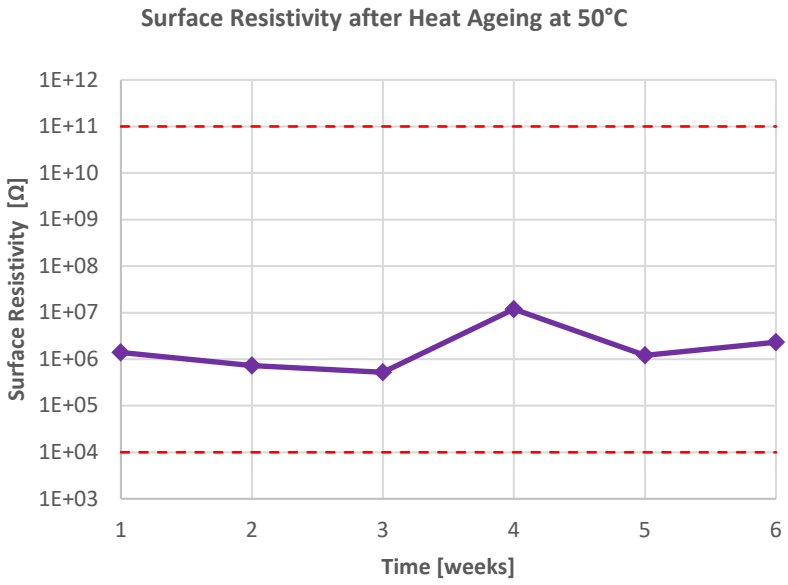

Figure 4: Changes in surface resistivity of Loctite® 3D IND3380 during 50°C heat ageing. The red dashed lines show the upper and lower limit for ESD properties.[8]

Throughout the heat ageing process, the surface resistivity remained consistently within range for ESD properties despite some variance from week to week. As parts in a production environment may be used for weeks or months on end, the ability to retain key properties is critical. More details regarding mechanical properties after heat ageing can be found on the Technical Data Sheet for Loctite® 3D IND3380 TDS.

Conclusion

Loctite® 3D IND3380 is a UV curable resin that can be printed to create ESD safe parts with great surface finish and a high temperature resistance. By printing designs, custom parts can be made quicker and cheaper than traditional molding or machining. The printing and post-processing procedure involves several variables, but Loctite® 3D IND3380 will consistently achieve ESD properties across a range of printers and post-processing steps. For more information on Loctite® 3D IND3380 or process parameters, contact us or visit www.LoctiteAM.com.

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