ADDITIVE MANUFACTURING IN PRINTED CIRCUIT BOARD ASSEMBLY PROCESSES

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ABSTRACT
Additive Manufacturing has recently been brought into the spotlight as an alternative manufacturing method. It is being frequently used across various industries for different applications. For Flex, a company that is heavily involved in the Printed Circuit Board (PCBA) process, 3D printing and additive manufacturing can play a role across the life cycle of the product. Due to the fact that 3D printing can allow the fabrication of parts in different materials and different geometries, its allows a rapid prototyping solutions combined with design freedom. In the PCBA process this is advantageous in the areas of manual assembly. When a product is designed and needs to be assembled, the auxiliary equipment such as floor space, capital equipment, work area and working tools need to be considered and planned for. These areas will have manual assembly areas where operators and resources will work on the product. When setting these areas for assembly and ultimately production, jigs and fixtures are required to be designed, fabricated, tested, finalized and then manufactured themselves for the assembly processes. These jigs and fixtures go through design iterative cycles so that they can accommodate the product in the best way. The iterative processes cost time, money and resources in the initial stages and then for the manufacturing of volume parts. By utilizing the strengths of 3D printing, the design process can not only be shortened, but the manufacturing of the jigs and fixtures can also be looked at to replace the cost and lead time of the traditional manufacturing process of the jigs and fixtures. For 3D printed jigs and fixtures to be considered as replacements for traditional jigs and fixtures, there needs to be a certain material characterization, and parts validation process involved to properly select the correct material, technology and process. This paper will compare different 3D printed materials and processes with traditionally manufactured jigs and fixtures.

Key words: 3D Printing, Additive Manufacturing, PCBA

INTRODUCTION
Contrary to popular belief 3D Printing and Additive Manufacturing are not the same thing, but can be used interchangeably for the sake of ease. 3D Printing, according to ASTM F2792- 12a "Standard Terminologies for Additive Manufacturing Technologies" is defined as "the fabrication of objects through the deposition of a material using a print head, nozzle, or other printer technology".

The process starts with a 3D model drawing that is done on any standard CAD software. This 3D model file is then converted into a stereolithography file format by either the native program or a 3rd party file converter. Some printers have this file conversion capability as part of their software suite for their printers. The file is then converted into G-Code or a language that the printer can understand, essentially creating the file into cross sectional slices of the part. This step is commonly known as "slicing".

Once the slicing of the drawing has been done the printer is ready to start the print. For nearly all 3D printers, the above process is the same, with the printing process itself being the main differentiator. In a Fused Filament Fabrication printer, once the 3D drawing is sliced, the printer can begin printing. The main components of the printer are, the print bed, the extruder, the hot-end, and the material. Material for this technology usually comes in a wire form on a spool. This wire filament is fed into the extruder, the extruder uses torque and pinch to control the speed of the filament being fed into the hot-end. Once the filament is in the hot-end, it is melted using heat.

The melted material is forced out of the hot-end by the extruder that is pushing in more material from the top. The hot-end, usually made of aluminum, deposits the melted material onto the build plate in a designated pattern as dictated by the software. As the material is being deposited by the hot-end, the build plate is moving in a X, Y or Z-axis depending on the part requirements of what is being printed. In some printers the build plate will stay stationary and the hot-end will move in a Cartesian plane to create the print. This process describes Fused Filament Fabrication (FFF), which is one of the technologies that the company currently employs.

Fused Filament Fabrication currently is used mainly for plastic materials. If metal printing is required, Direct Metal Laser Sintering is utilized to print metal parts. The process of creating a 3D model to be understood by Direct Metal Laser Sintering printers is as described above, however, the process of printing is vastly different. Metal printers are usually larger in footprint due to the high quality components and the auxiliary processes required to ensure effective operation of the machine as well as quality of the print. The main components of a metal are the build plate, recoater, laser and powder.

Before a metal part is printed, the build chamber will fill up with an inert gas, usually Argon. This is to ensure that no oxidation occurs during the process. The build plate where the powder is residing and the recoater blade will be leveled. This can be done manually, but most printers can be automatically calibrated to level before a print starts. After the components are leveled, the print can start. A laser will sinter the powder in the cross-sectional geometry of the part. Once the sintering for that level has finished, a recoater blade that was located off to the side of the build area will move over the sintered layer and coat a new layer of powder on top.

The layer of powder that is recoated onto the sintered layer is very important to the integrity and quality of the print. If too much powder is recoated, the layer below and the layer above may not be sintered together well by the laser. If there is too little powder, the laser might sinter already sintered powder, causing varying layer heights in the print. The even distribution of powder and the correct amount of powder is a key area that currently affects how the powder is recoated on top of itself. Layer by layer powder will be recoated and sintered by the laser until the part is complete.

Material Jetting processes are very similar to the above. Resin is loaded into a printer, where it travels into a printhead, the print head has several nozzles or resin dispensers (much like a 2 dimensional inkjet printer). The resin is then extruded from the miniaturized nozzles onto a build platform in the 2 dimensional cross section of the part. After, the layer is passed over with a UV light source or other light activation that cures the resin that was deposited. The printhead then deposits another layer on the previously cured layer, this is done repeatedly until the part is completed.

MATERIALS EVALUATED
There are a number of materials that are available for 3D printing for various engineering uses. Various vendors offer over hundreds of different materials that are either specific to an application or to a specific desired characteristic. For the purpose of this study 8 materials that are regularly used for engineering applications were evaluated and characterized to determine which can be used in Printed Circuit Board Assembly processes. A table regarding the material identifying characteristic as well as the designation is below.

Table 1: List of materials evaluated for this study

ID	Identifying Characteristic
A	Black
B	Clear
C	Transparent
D	High Strength
E	Blue
F	Super High Strength
G	High Temp
H	Plastic Like Material

TESTS PERFORMED
To properly characterize the materials that could be used for engineering applications, various tests were chosen and performed so that a decision tree could be created. The ultimate goal of the project is to be able to have a decision tree that can determine which material can be used for a specific application. The description as well as motivation to perform each test is below.

Thermal Mechanical Analysis
This test is performed to check the dimensional stability of a test specimen as well as calculate its Tg. The results of this test are important due to the fact that they will indicate how the 3D printed specimen maintains its dimensional stability. For materials to be used in PCBA processes, all auxiliary components must retain their mass as well as dimensional accuracy.

Thermal Gravimetric Analysis
Thermal Gravimetric Analysis is performed to determine the temperature when the material, in this case, the test specimen, has lost 5% of its weight. For this study, the temperature used was 300°C. The results taken from this test help indicate the lifespan of a material, the faster it loses its weight, its lifespan decreases.

Thermal Life Cycle Test
For this test, the 3D printed test specimens were subjected to 200 cycles of a predetermined temperature profile. Each cycle was the same in duration of time. The results of this test show what happens to a 3D printed test specimen when subjected to high temperatures. Any indication of warpage, delamination, degradation or other visible and/or cosmetic damage is important to capture. The results from this test indicate which materials are suited for high temperature applications in the PCBA process.

Density Test

This test is a calculation based on the various parameters of a test specimen. The density was checked after thermal and chemical resistance testing. The results of this test are used to determine how well the test specimen is able to hold its mass after being subjected to either chemical or thermal stresses. The density check of test specimens helps determine which application it is suited for.

Chemical Resistance Test

The chemical resistance test is performed by subjecting the material to various chemicals. The test specimens are submerged in a chemical solution for a given period of time and then are subjected to a drying cycle for a given period of time. This test is important in the material characterization process due to it being an indicator of how the materials will react in various chemical exposure applications.

ESD Check

Electrostatic Discharge Check is a very crucial test in the characterization process since this determines whether or not the 3D printed material can be used with or around live PCBs or any other components that carry a charge. The values obtained with the ESD check for each of the materials assist in the ranking of the materials for application use.

Flexural Test

Flexural Testing is performed by taking a test specimen and checking the materials ability to resist deformation under a specified load. This is a significant destructive test since the results of this test indicate how well a material can perform under mechanical stress but how well it can retain its dimensional accuracy. If the material does not break but bends or deforms under a load, the value or threshold at which this occurs helps guide which application the 3D printed material is well suited for.

Thin Wall Flexural Testing

Thin Wall Flexural testing is performed by taking a thinner specimen and subjecting it to load to check the material's ability to resist deformation. This test is different from the standard flexural test in the sense that it helps identify how the 3D printed materials react with thinner walls and less material support. The mechanical stress that the test specimens are subjected to help determine how well the specimens retain their dimensional accuracy. The results from this test also help guide which applications each of the materials are suited for. As with Flexural Testing, any bending, breaking, deformation, delamination or other functional and/or cosmetic effect is recorded.

X – Ray Analysis

The test specimens were placed in a X – Ray machine before and after tests to determine if and how they are affected by various tests. The significance of this analysis is that the results can accurately reflect how the test specimen has reacted in various conditions. The results of this test are qualitative in nature and represented by pictures taken of the test specimens.

Qualitative Analysis – Optical Checking and SEM

Throughout the process of the material characterization, various optical recordings were performed such as pictures taken of the test specimens, X – Ray analyses done, as well as Scanning Electron Microscope pictures and measurements. The results of these tests and analyses are to provide a deeper understanding of what happens to the 3D printed materials under various conditions and helps guide the application decision process.

RESULTS
Thermal Mechanical Analysis

					CTE Z - axis below Tg (ppm/°C)	CTE Z- axis above Tg (ppm/°C)
Test 1 TMA						
Dimension Change						
ID	**Tg (°C)**	**CTE(X-Axis)ppm/°C**	**CTE(y-Axis)ppm/°C**	**% TE on Z**		
A	75.14	147	157.8	3.43%	59.1	174.65
B	71.67	158.2	158.6	3.27%	55.93	162.6
C	77.32	142.2	151.2	3.42%	25.76	173.05
D	76.08	138.1	153.75	3.53%	141.6	180.1
E	71.48	143.2	140.9	3.64%	99.2	189.55
F	79.65	157.55	158.75	3.42%	151.65	176.7
G	78.34	161.7	173.45	3.54%	98	182.55
H	79.2	208.3	233.35	8.31%	97.94	437.1

Figure 1: Results

Thermal Gravimetric Analysis

ID	Average of Temperature at 5% weight loss (°C)	Average of Weight loss at high temperature (%)
A	276.44	8.36
B	285.73	7.57
C	289.16	6.99
D	282.51	7.03
E	276.25	7.81
F	304.63	4.42
G	299.96	5.07
H	296.57	5.19

Figure 2: Results

Thermal Life Cycle Test

Test 3 Thermal		
Specimen ID	Warpage	Weight change %
A	0.372	18.03%
B	0.354	8.63%
C	0.146	26.47%
D	0.74	9.46%
E	0.471	26.39%
F	0.095	4.19%
G	0.452	4.73%
H	0.269	14.05%

Figure 3: Results

Density Test

Specimen ID	Chemical Test Density		
	Density Before	Density After	% Change
A	0.00114	0.00113	1.26%
B	0.00116	0.00114	1.69%
C	0.00114	0.0011	2.97%
D	0.00114	0.0011	3.90%
E	0.00114	0.0011	3.82%
F	0.00115	0.00114	0.54%
G	0.00114	0.00113	0.70%
H	0.00115	0.00107	7.59%

Figure 4: Results

Chemical Resistance Test

Specimen ID	Thermal Test Density		
	Density Before	Density After	% Change
A	0.00116	0.00113	1.91%
B	0.00116	0.00112	3.63%
C	0.00114	0.00109	4.29%
D	0.00114	0.00112	1.55%
E	0.00115	0.0011	4.34%
F	0.00115	0.0011	3.84%
G	0.00114	0.0011	3.38%
H	0.00115	0.00086	25.46%

Figure 5: Results

ESD Check

				Test 6 ESD							
Initial(S/N,1-10)				After Thermal(S/N,1-5)				After Chemical(S/N,6-10)			
Top	Bottom	Side1	Side2	Top	Bottom	Side1	Side2	Top	Bottom	Side1	Side2
9.13E+10	2.00E+11	2.39E+11	2.34E+11	1.37E+11	2.45E+11	1.02E+11	1.20E+11	7.33E+10	4.96E+10	4.50E+10	3.43E+10
8.10E+10	1.07E+11	1.66E+11	1.04E+11	7.86E+10	9.78E+10	1.32E+11	1.40E+11	1.22E+11	1.08E+09	1.46E+11	8.70E+10
9.56E+09	1.06E+11	7.90E+10	8.12E+10	1.39E+11	1.34E+11	9.30E+10	1.06E+11	5.88E+10	1.34E+11	1.96E+11	1.51E+11
2.55E+10	5.54E+10	7.70E+10	8.54E+10	1.57E+11	1.37E+11	2.24E+11	2.13E+11	1.27E+11	4.78E+10	5.78E+10	3.85E+10
6.81E+09	3.34E+10	3.57E+10	3.08E+10	8.74E+10	4.32E+11	2.59E+11	2.41E+11	8.63E+10	1.16E+11	3.73E+10	1.57E+11
9.42E+10	1.18E+11	1.25E+11	1.20E+11	8.10E+10	9.36E+10	8.78E+10	8.30E+10	3.37E+10	8.03E+09	1.47E+10	2.19E+11
9.46E+10	1.10E+11	2.92E+11	2.92E+11	1.40E+11	1.68E+11	2.00E+11	1.62E+11	2.82E+10	1.95E+10	2.09E+10	5.63E+09
2.49E+10	1.24E+11	1.26E+11	1.82E+11	1.01E+11	9.63E+10	1.09E+11	1.66E+11	6.92E+09	5.40E+09	7.88E+10	1.70E+10

Figure 6: Results

Flexural Test
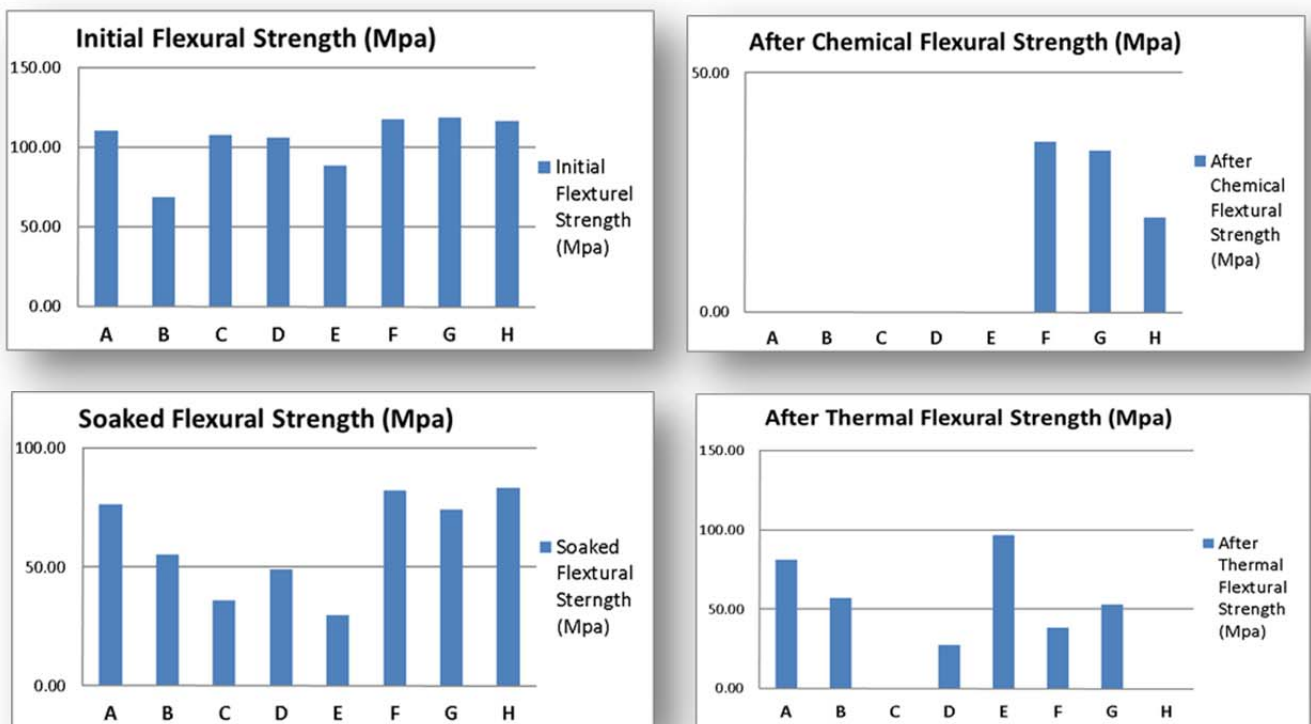
Figure 7: Results

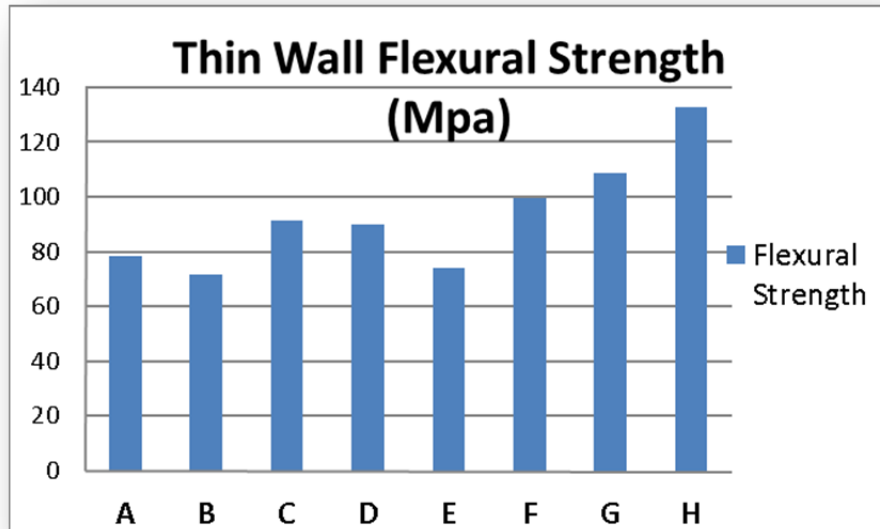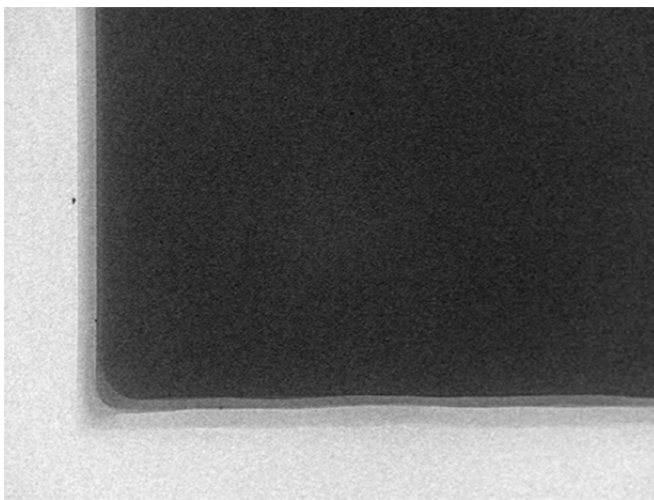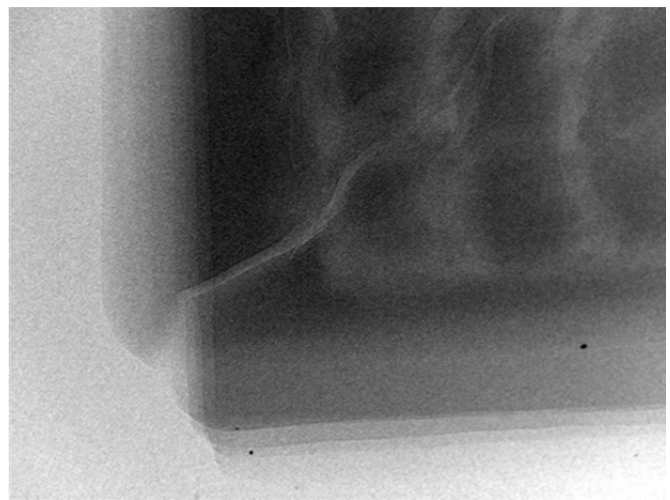**Thin Wall Flexural Testing**

Figure 8: Results

X – Ray Analysis

Test Specimen before any tests   Test Specimen after high temperature

Figure 9: Results
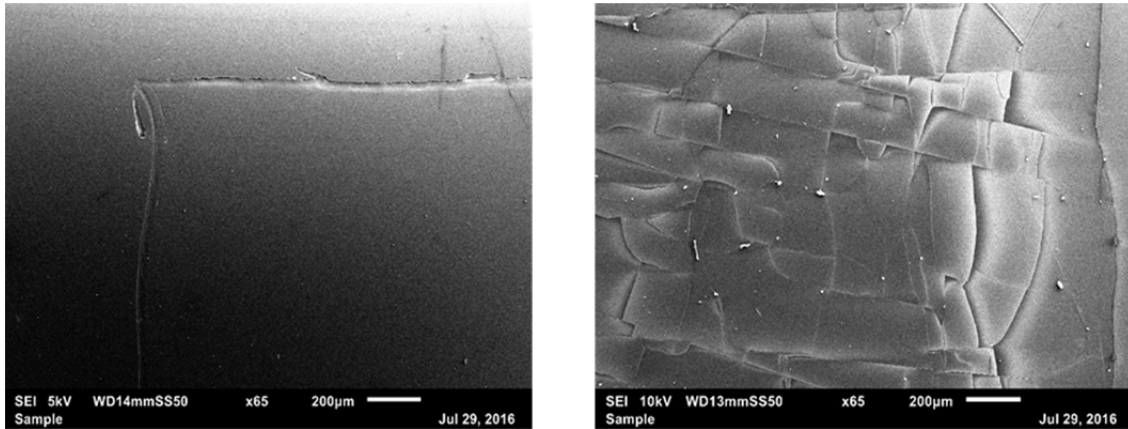
Qualitative Analysis – Optical Checking and SEM

Figure 10: Results

Summary of All Test Results

Specimen ID	Test 1 TMA	Test 2 TGA	Test 3 Thermal	Test 4 Density	Test 5 Chemical	Test 6 ESD	Test 7 Flexural	Test 8 Thin Wall	Qualitative Analysis
A	4	8	6	1	3	8	4	6	1
B	2	6	2	4	4	6	6	8	1
C	1	4	5	6	8	3	8	4	8
D	3	5	7	5	2	7	7	5	1
E	6	7	8	7	5	4	5	7	1
F	5	1	1	3	6	1	1	3	1
G	7	2	3	2	7	5	2	2	1
H	8	3	4	8	1	2	3	1	1

Figure 11: Results

CONCLUSIONS

From our testing we were able to see that the material that has the highest number of favorable rankings is material F. This material was able to perform well under thermal and flexural tests, therefore opening up applications that require these types of characteristics. The material that had the second highest number of favorable rankings was material G with material H following with third highest.