Injection Molded Structural Electronics Brings Surfaces to Life

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Abstract

This paper introduces IMSE technology enabling smart molded structures. (IMSE stands for Injection Molded Structural Electronics.) Smart molded structures are made by integrating and encapsulating printed electronics and standard electronic components within durable, 3D injection-molded plastics. IMSE technology and manufacturing differ from conventional electronics. Thus, TactoTek uses its internal IMSE Technology Validation process for certification of components, surface mounting adhesives and other materials. IMSE Technology Validation process includes also extensive reliability testing to ensure that IMSE solutions are reliable.

Key words: Structural electronics, printed electronics, validation process, reliability

Introduction to IMSE Technology

IMSE technology enables design innovation by integrating electronic functions into 3-dimensional injection molded plastic structures. Features, such as controls, sensors, illumination and communications, are embedded in thin 3D structures with plastic, wood and other surfaces.

The structures are light, thin and durable. In conventional use cases, such as an in-vehicle control panel, a single part replaces a multi-part conventional electronics structure and eliminates labor-intensive electro-mechanical assembly. The part also weighs less and is significantly thinner. TactoTek has demonstrated structural electronic designs with 70% weight and 90% thickness reduction when compared with conventional multi-part assemblies (Figure 1).

Introduction to IMSE Manufacturing

Typical IMSE solution consists of electronic film on the bottom carrying conductive inks, dielectrics, and surface mounted electronic components. On the top, there can be either surface film with decorations or a natural surface such as wood. Everything is injection molded to one-piece assembly. Figure 2 shows an illustration of materials in IMSE design.

Depending on the use case and functionality, IMSE part can be also a 1-film design. One-film design has an electric film on the back or front side of the part. When using only back-side-film, we create visual surface by post process on top of injection molded resin. When using only front-side-film, we print both graphics and electronics onto the same film.

Figure 1: TactoTek has demonstrated IMSE designs with 70 % weight and 90 % thickness reduction when compared with conventional multi-part assemblies.

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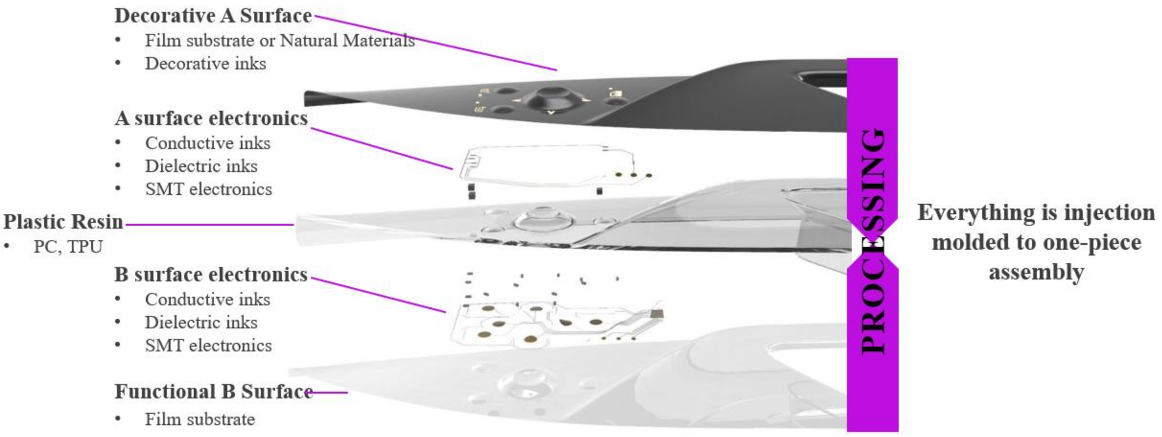

Figure 2: Illustration of materials in IMSE design.

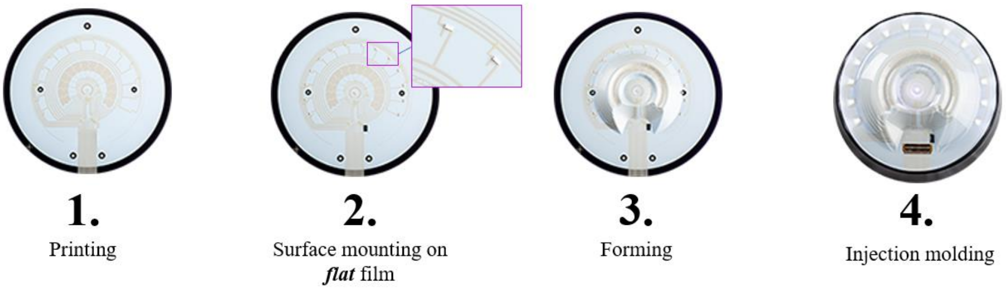

Figure 3: Core manufacturing processes for IMSE

Core manufacturing processes for IMSE are printing, surface mounting, forming and injection molding (Figure 3). Taken individually, these processes are mature and TactoTek uses standard equipment suitable for mass production. However, the standard processes are combined in a unique way during manufacturing of IMSE.

Printing is the first core manufacturing process and TactoTek uses screen printing technology. Screen printing is suitable for mass-production and enables appropriate layer thickness (range of 10 µm). Electronics (functional inks) and decorations (graphic inks) are screen printed onto plastic film or another suitable substrate material. Electronics are typically printed using silver (Ag) conductive inks and dielectric inks to insulate between layers of circuitry.

Surface mounting is the second core process. Components are placed and bonded, mechanically and electrically, onto electronic films. IMSE structures use isotropically conductive and structural adhesives for component bonding. The output is two-dimensional film substrate with components.

Forming is the third core process and TactoTek uses a high-pressure thermoforming process. Two-dimensional electric and graphic films are thermoformed into three-dimensional shape and trimmed as needed. Outputs are 3D electric films with components and 3D graphic films. Forming is not used in conventional electronics manufacturing. During forming, component packages are subjected to elevated temperatures and pressures. The maximum temperature depends on the polymer film and is typically below 150 C. Maximum pressure is typically below 8 MPa (80 bar).

Injection molding is the fourth core manufacturing process. Three-dimensional electric films and 3D graphic films are used as inserts in an injection molding tool. Resin, such as polycarbonate is injected between the films resulting in a single molded part. The output is a strong and durable structure in which electronics are encapsulated within the molded plastic. Injection molding is not used in conventional electronics manufacturing, either. Some molding temperatures are higher than peak temperature during reflow soldering of SAC-solders. In addition, heat transfer from hot resin to electric films is through conduction. Thus, heat transfer to components and other materials is more efficient than during reflow soldering. Maximum pressures during injection molding are around 100 MPa (1000 Bar).

IMSE manufacturing often includes also pre-assembly and final assembly of control electronics. These processes are similar to conventional electronics components.

Requirements for an Ideal Component

The 2-film design can be illustrated also as a material stack, Figure 4. By material stack we mean the combination of films, inks, electronic components, surface mounting adhesives and injection molding resin.

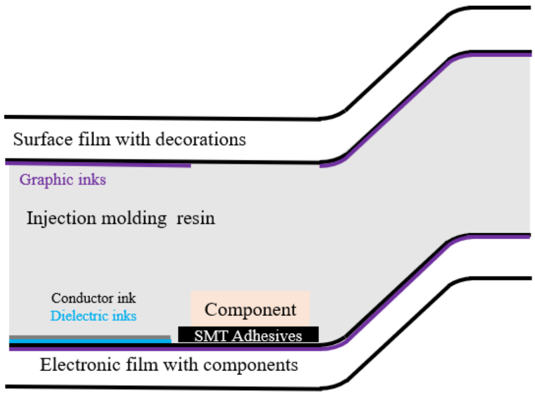

Figure 4: Illustration of a material stack in a 2-film design

Currently most electronic components are optimized for conventional electronics manufacturing that does not include the temperature and pressure exposure of thermoforming and injection molding processes. TactoTek has therefore determined requirements for an ideal component package [1]. By ideal component package we mean that it does not lower IMSE manufacturing yield, product reliability or impose significant design constraints. The requirements for the ideal component package are listed below and partly illustrated in Figure 5.

1. Minimum contact spacing is 500 μm.
2. Minimum contact area is 500 μm x 300 μm.
3. Contact surfaces are clean. For example, there are no mold release agents or oils.
4. Component package substrate is structurally strong, such as glass fiber laminate or copper/bronze baseplate.
5. No package materials are sensitive to moisture. The moisture sensitivity level (MSL) is 0 or 1.
6. Component package does not have any cavities or hollow parts. The use of porous materials, such as low-fired ceramics, is also minimized.
7. Maximum package overall height is 1.0 mm.
8. Bottom of component package is flat and has room for bonding. Structural adhesives, such as epoxies, have good adhesion to bottom of component package.
9. Package shapes are simple, such as cuboids, cylinders or domes. All corners are rounded.
10. No wire bonding is exposed.
11. Maximum package size is 16 mm^2.
12. Package material has good adhesion to injected polymer resin, such as polycarbonate (PC), PET or TPU.
13. Maximum amount of contact pads is 16. (This requirement is a combination from requirements 1, 2 and 11.)

IMSE Technology Validation Process

IMSE Technology Validation process includes certification processes for conductive inks, electronic components and surface mounting adhesives. In addition, the total material stack is validated in Material Stack Platform (MSP). MSP test structures include all IMSE materials and undergo all IMSE core processes. In this paper, we present the certification processes for components and surface mounting adhesives.

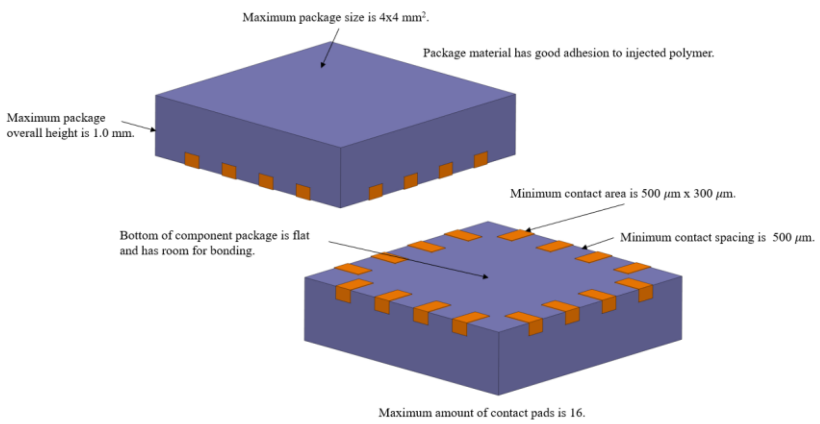

Figure 5: Requirements for ideal component package

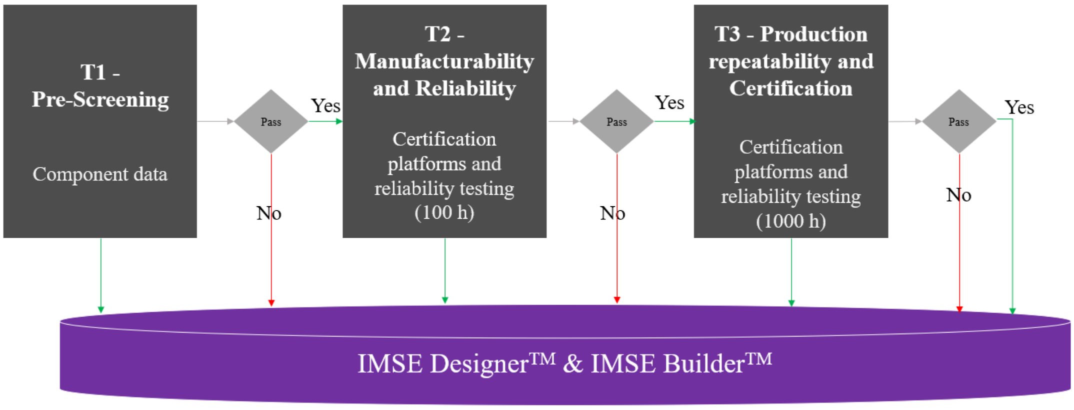

Figure 6: Component certification process

Component Certification Process

TactoTek certifies all electronic components that are embedded inside injection molded polymers. Certification has three steps, Figure 6. During Pre-Screening component data is compared with the ideal package. The component package does not need to fulfill all requirements to pass this step. However, there are some items that cause failure at Pre-Screening. For example, a package with moisture sensitivity level (MSL) of 4 or higher fails.

If a component passes the pre-screening (T1), TactoTek manufactures certification platforms with that component using internal company standards for layout and material stack. The T1 manufacturing lot includes a total of 200 components, or more. Components undergo surface mounting, forming and injection molding and they are tested after each process step. The certification platforms are subjected to reliability testing, as well. Typical environmental loads are change of temperature as well as elevated temperature and elevated temperature-humidity. Testing time is 100 hours or more.

If component passes T2 step, TactoTek manufactures more certification platforms. The T3 manufacturing lot includes at least 10 000 components so that TactoTek can assess production repeatability. Some of the certification platforms are subjected to reliability testing. Tests are the same as during T2 and testing time is increased to 1000 hours or more. Based on manufacturing yield, reliability testing and physical failure analysis, component can pass T3 step and receive IMSE certification.

Surface Mounting Adhesives Certification Process

By surface mounting adhesives we mean isotropically conductive and structural adhesives used for electrical and mechanical bonding of components, Figure 7. Typically, they are optimized for conventional electronics manufacturing that does not include the temperature and pressure exposure of thermoforming and injection molding processes. TactoTek has therefore identified critical-to-quality requirements for surface mounting adhesives. They are listed below:

1. Adhesive is compatible with typical TactoTek stack materials, see Table 1.
2. Adhesive can be applied by stencil printing, pin transfer or by (jet) dispensing. It is an advantage if adhesive is suitable for many application methods.
3. Adhesive cures during TactoTek reflow, typical peak temperature is 130 °C and profile length is about 3 minutes.
4. Adhesive working life is 72 hours or more.
5. Adhesive storage life is 3 months or more.
6. Isotropically conductive adhesive has resistivity less than 5 mΩ·cm.
7. It is an advantage if adhesive is solvent free.

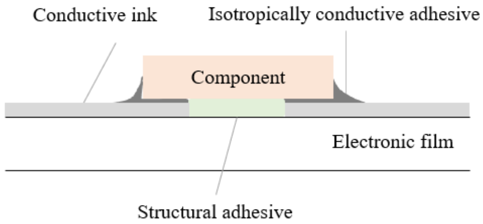

Figure 7: TactoTek uses isotropically conductive and structural adhesives for surface mounting

Table 1: Typical TactoTek stack materials

Film substrate	Polycarbonate films are most common materials
Graphic inks	Film-Insert-Molding ink families from Pröll, Nazdar and Marabu
Functional inks	In-Mold-Electronics families from Dupont, Henkel, Sun Chemical and Nagase

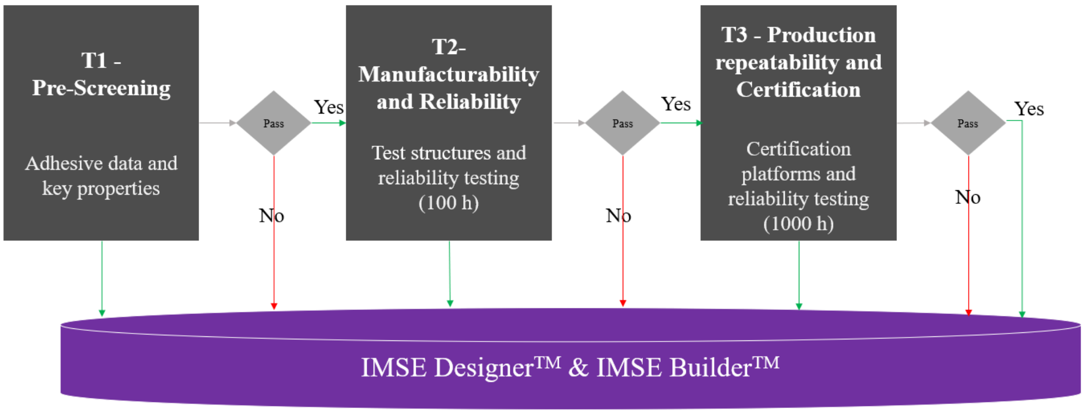

Figure 8: Surface mounting adhesive certification process

Steady-State Temperature-Humidity 85C/85%RH (JEDEC 22-A101) for 1000 hours 26 MSPs were tested, • 18 were all powered on • 8 were powered off	High Temperature Ageing at 110 C for 1000 hours 19 MSPs were tested, they were all powered off	Rapid Change of Temperature between -40 C and +85 C * (IEC 60068-2-14) for 1000 cycles 20 MSPs were tested, they were all powered off

Figure 9: Summary of reliability testing in MSP validation

TactoTek certifies surface mounting adhesives, as well. The certification is similar to component certification process and has three steps, Figure 8. During pre-screening, adhesive data is compared with critical-to-quality requirements. We also make quick trials to ensure that adhesive is compatible with typical stack materials and that it cures in TactoTek curing process (130 C for about 3 min).

If adhesives pass T1, TactoTek manufactures test platforms using 0 Ω - resistors. They undergo surface mounting, forming and injection molding. The resistance values are measured after each process step. The test structures are subjected to reliability testing, as well. Typically, tests are same as in component certification. Testing time is 100 hours or more.

If adhesives pass T2 step, TactoTek manufactures certification platforms using components, such as LEDs. They undergo surface mounting, forming and injection molding. Some of the certification platforms are subjected to reliability testing. The testing time is increased to at least 1000 hours. Based on manufacturing yield, reliability testing and physical failure analysis, adhesives can pass T3 step and receive IMSE certification.

Reliability Testing Results - Material Stack Platforms

The results presented here are from validation of Material Stack Platforms (MSPs). In this case, the components were two different types of LEDs. Type1-LED is top-shooting and Type2-LED is side-shooting. MSPs included also structures for measuring resin transparency.

A total of 65 MSPs were tested in three different reliability tests, Figure 9. We data-logged LED forward voltage (V_f) for one LED in each MSP that was powered on, Figure 10. We also measured LED brightness (i.e. maximum and mean intensity) as well as LED color coordinates before and after reliability testing.

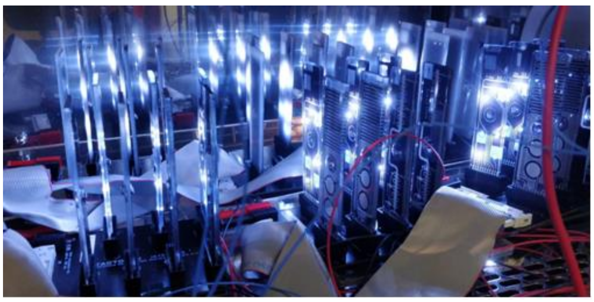

Figure 10: Photo of the MSPs that were powered on during Steady-State Temperature-Humidity (85/85) testing

All of the tested LEDs remained functional during testing and LED forward voltage (V_f) remained constant, as well. In addition, the color coordinates before and after testing had nearly the same values. We did, however, see a luminance decrease in both types of LEDs. For Type1-LEDs, it was most noticeable in High Temperature Aging.

Their luminance values after testing were about seven percent lower than before testing. For Type2-LEDs, the luminance values decreased significantly after Steady-State Temperature-Humidity test. The transparency of the injection molding resin had not changed during testing. Thus, we assume that the luminance decrease is caused by delamination between LED encapsulant and injection molding resin. We are currently making root-cause analysis to confirm this assumption.

Reliability Testing results - Extended Testing

Testing until failure is useful for better understanding reliability. That is why we tested one of the company demonstrator products for 3000 cycles in the change of temperature test. The demonstrator product, shown in Figure 11, contains 20 pieces of Type2-LEDs. Figure 12 shows summary of the tests and sample sizes.

Figure 11: Photo of a demonstrator product that was subjected to extended reliability testing

Change of Temperature
between -40 C and +85 C *
(IEC 60068-2-14) for 3000 cycles

20 pcs of Type2-LEDs were tested,
they were all powered on (I=15 mA).

*Test cycles had 1 h exposure (i.e. dwell) times and 1 hour ramp times. One test cycle lasted for 4 hours.

Figure 12: Summary of extended reliability test

Two Type2-LEDs failed during 3000 cycles. Failures occurred at 702 and at 2988 cycles. When we fit this data into a Weibull distribution, we predict 50 percent failure point at over 10000 cycles, Figure 13. Such a high value demonstrates the reliability of the technology.

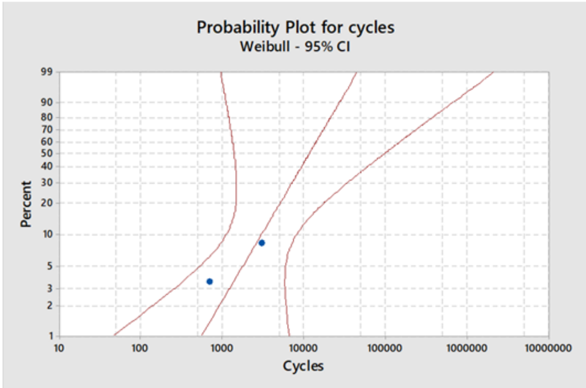

Figure 13: Extended reliability testing failures in Weibull-distribution

We performed cross-section and scanning-electron-microscope (SEM) analysis on a failed Type2-LED. It showed that the failure mode is a fracture in the conductive adhesive used for surface mounting, Figure 14. The failure mechanism is conductive adhesive creep caused by thermo-mechanical stresses during thermal cycling.

However, the number of tested components was small in the extended reliability testing. Thus, we have tested another demonstrator product with 20 Type2-LEDs. After 1362 cycles, all LEDs have remained functional and the test continues.

We have shared also reliability testing results from component certification platforms [2]. Tests and test durations were similar to MSP reliability testing. Components endured thermo-mechanical stresses and elevated temperature-humidity without failures as long as designs were according to TactoTek design guidelines.

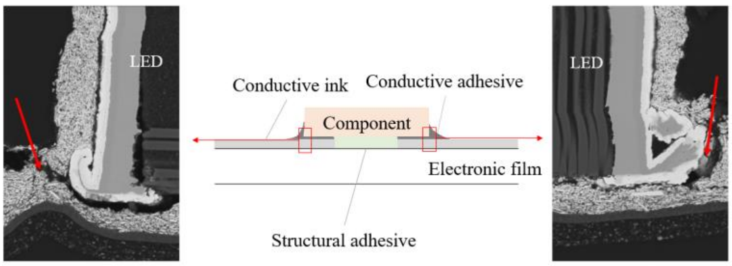

Figure 14: SEM-images of the cross-section show fracture in the conductive adhesive

Conclusion

TactoTek has demonstrated IMSE designs with 70 % weight and 90 % thickness reduction when compared with conventional multi-part assemblies. Because IMSE manufacturing is different from conventional electronics, TactoTek uses its internal IMSE Technology Validation process. It includes certification of conductive inks, electric components and surface mounting adhesives. TactoTek uses also Material Stack Platforms (MSPs) to certify injection molding resins.

The results from MSP reliability testing show that LED components pass tests such as 1000 hours in Steady-State Temperature Humidity, High Temperature Testing and Rapid Change of Temperature. Injection molding resin strengthens the structures and also protects electronics from environmental conditions, such as moisture, and thermo-mechanical stresses.

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References

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