Analysis of LED wire bonding during encapsulation process

Hafiz Roslan¹, M.S. Abdul Aziz¹⁎, M.Z. Abdullah¹, R. Kamarudin¹, M.H.H. Ishak², F. Ismail², Agustinus Purna Irawan³

¹School of Mechanical Engineering, Engineering Campus, Universiti Sains Malaysia, 14300 Nibong Tebal, Seberang Perai Selatan, Penang, Malaysia.
²School of Aerospace Engineering, Engineering Campus, Universiti Sains Malaysia, 14300 Nibong Tebal, Seberang Perai Selatan, Penang, Malaysia
³Faculty of Engineering, Universitas Tarumanagara, Indonesia

⁎Corresponding author: msharizal@usm.my

Abstract. The encapsulation process is crucial since its act as first layer protection for the LED. The encapsulation process also influences the quality of the product. The structure of the encapsulate will affect the quality of emitting light in term of brightness and color. Thus, the process of encapsulation is one of the factors that can improve the quality of the product. This study aimed to observe the encapsulation process of LED and the interaction between gold wire bonding and EMC. By considering the computational method using Fluid-Structure Interaction (FSI), the VOF was used to simulate the dispense of EMC during the encapsulation process. Besides, an experiment was conducted to validate the simulation result. Thus, the FSI was utilized to predict the amount of stress on to the gold wire bonding during the encapsulation process. The broken gold wire bonding that connects these two elements indirectly will cost the failure of the product to work as intended. Keywords: LED, encapsulation process, computational method.

1. Introduction
The light-emitting diode (LED) is the most advance technology in the lighting industry. High power LED rapidly expanding in term of usage since it can last long up to 11 years. Other than that, the efficiency of the LED much better compare to different light sources items. There are a few types of LED encapsulation structure available in the market. The structure of encapsulation depends on the type of LED itself. In this study, high power LED is used, and the typical structure of high-power LED is semi-sphere, as shown in Figure 1.

Encapsulant used in this study is Epoxy Molding Compound (EMC). The excellent electrical properties on EMC are the reasons EMC used in various applications, primarily in the electrical and automotive industry [2]. In the other hand, EMC has high reliability when dealing with high-temperature applications. The dispensing of EMC is simulate using Volume of Fluid (VOF) method in ANSYS FLUENT software since this software containing comprehensive physical computing capability needed for flow modeling, turbulence, heat transfer and many more. The encapsulation process is important in the LED manufacturing process since the encapsulant will act as the first shield to protect the inner parts of the LED from defect. Other than that, the structure of the encapsulant gives the significant effect of LED efficiency. Upon the encapsulation process, the volume of EMC dispense onto the LED is crucial to avoid the excessive or insufficient amount of EMC. Acknowledge the importance of this area which contains the tiny gold wire that connected to the PCB. An excessive amount of EMC will create
more stress on gold wire bonding and effect the interconnection between the gold wire and the PCB. In the other hand, an insufficient amount of EMC will lead to poor quality of the light emitted by the LED. The study aims to determine the suitable amount of encapsulate (EMC) and appropriate viscosity of encapsulant used during the encapsulation process. The simulation of the encapsulation process (amount of EMC dispensed onto LED) and the time required for the process is done by utilizing the VOF technique. Finally, the results of the simulation are compared with the experimental result for the validation purpose.

![Figure 1. Typical LED Encapsulation Structure [1]](image)

2. Methodology

2.1 Governing equation

In this study, the method used to analyze the LED encapsulation process is computational fluid dynamics (CFD) which uses numerical analysis and data structure to solve the problem. This study will VOF technique and the FSI method to analyze the EMC dispensing into LED and the interaction of gold wire with the EMC during the encapsulation process. The first part of this analysis is focused on the EMC dispensing method that describes the movement of EMC in the simulation using an incompressible 3D transportation equation that is a continuity equation, Navier-Stokes equation and energy conservation as written:

The continuity equation is shown as follow [12].

\[
\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0
\]

where \( u, v \) and \( w \) are velocities in \( x \)-, \( y \)- and \( z \)- axis respectively.

The Navier-Stokes equations in the \( x \)-, \( y \)- and \( z \)-direction is shown as follow [13].

(x-direction)

\[
\rho \left( \frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + w \frac{\partial u}{\partial z} \right) = - \frac{\partial P}{\partial x} + \eta \left( \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2} \right) + \rho g_x
\]

where:

- \( \rho \) = density
- \( u \) = velocity vector
- \( P \) = static pressure
- \( t \) = time
- \( \eta \) = viscosity
- \( g_x, g_y, g_z \) = gravity in \( x \)-, \( y \)- and \( z \)-axis

Similar equation is applied for the \( y \)- and \( z \)-directions.

Energy equation:
\[
\rho c_p \left( u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} + w \frac{\partial T}{\partial z} \right) = k \left( \frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} \right)
\]

The EMC is heated for 15 minutes for deformation at a high temperature. Thus, EMC viscosity at high temperatures is almost constant. Therefore, the Newtonian fluid equation can be defined \cite{12}:

\[
\eta = \frac{\tau}{\gamma}
\]

where: \(\tau\) = shear stress  
\(\gamma\) = strain rate

### 2.2 Computational setup

The application of the CFD modelling to the LED encapsulation process could improve the understanding of fluid behavior and predicts the flow of EMC during the dispensing process onto the LED. The VOF was used to track the flow of the EMC during the dispensing process. A 3D domain consists of 2 parts of a solid body (gold wire and chip and the domain) was optimized and meshed with a quadratic element order total of 114768 nodes and 80101 elements illustrated in Figure 2. Table 1 and Table 2 shows the Material properties and boundary condition setup for the modelling purpose.

| Table 1. Material Parameters |
|-------------------------------|
| Properties                    | Epoxy Molding Compound |
| Density (kg/m³)               | 1800                   |
| Viscosity-i (kg/m.s)          | 3                      |
| Viscosity-ii (kg/m.s)         | 5                      |
| Viscosity-iii (kg/m.s)        | 6                      |
| Surface Tension (N/m)         | 0.047                  |

| Table 2. Boundary Condition   |
|-------------------------------|
| Boundary Condition at Fluent  | Details |
| Inlet Speed (m/s)             | 2.58    |
| Injection Time (s)            | 0.002   |
| Inlet Contact Angle (degree)  | 175     |
| Inlet Diameter, a (mm)        | 0.6     |
| Base Diameter, b (mm)         | 4       |
| Distance Needle to Base, c (mm)| 5     |

A significant factor of CFD simulation research is the optimum number of meshing elements or nodes. Time needed to compute the problem is different depends on the total number of mesh...
element or nodes. To choose the right mesh element size before simulation analysis, 4 different models were examined: mesh-i (15mm), mesh-ii (20mm), mesh-iii (25mm) and mesh-iv (30mm). Table 3 show the number of elements and nodes in each types of mesh.

| Mesh type      | Nodes   | Elements | Time (min) |
|----------------|---------|----------|------------|
| Mesh-I (15mm)  | 263557  | 187153   | 35         |
| Mesh-ii (20mm) | 114768  | 80101    | 23         |
| Mesh-iii (25mm)| 60089   | 41240    | -          |
| Mesh-iv (30mm) | 35835   | 24177    | -          |

The selection of mesh type is based on the complexity, accuracy and time taken for each mesh to complete the calculation for 1e-6 times step size. The time taken for the fluid to reach the bottom of the geometry where the LED chip located is recorded. For mesh-iii and mesh-iv, there are inaccurate of meshed geometry occur since the element size too big for the mesh to be compatible. Figure 3 shows the error’s part of mesh for both type mesh-iii and mesh-iv. Thus, both types of mesh excluded from testing part. Next, mesh-i and mesh-ii are set to run the test simulation. The time taken for mesh-i to achieve the target is longer than mesh-ii. Observed the fluid volume of fraction for mesh-i and mesh-ii, there are no significant differences that affect the result obtained. Conclude the result, mesh with an element size of 20 mm (mesh-ii) was chosen to be run in full analysis in this study.

The apparatus and material used to conduct the experiment is the rectangular tank, syringe, 0.6mm needle, vacuum pump, pressure gauge, LED, and the EMC) as shown in Figure 4. A syringe

2.3 Experiment setup

![Figure 3. Mesh error in type iii and iv.](image1)

![Figure 4. Experiment Setup of LED Encapsulation](image2)
containing a specific volume of EMC is injected through a hole on top of the tank. The process of encapsulation is recorded using a high speed camera. Then the experiment results are compared with the simulation result. The LED is placed on top of the plate to meet the required distance between LED and needle.

3. Result and Discussion

There are 3 types of viscosity used in this simulation which are 3 kg/m.s, 5 kg/m.s and 6 kg/m.s. The results were observed, and the comparison of the structure of EMC is made during the simulation and experimental. The objective of the simulation is to ensure the volume of EMC fully cover the base of LED, which approximately 4mm in diameter. The final structure of EMC is expected to be similar to the actual result. Figure 5 illustrates the comparison between the simulation and experimental results. The covered area of EMC for 5 kg/m.s and 6 kg/m.s more likely to be accurate compared to 3 kg/m.s of viscosity. Hence, in this design of geometry 3 kg/m.s viscosity not suitable compared to other two types. The viscosity of 5 kg/m.s and 6 kg/m.s appear like the hemisphere shape as obtained in the experimental result. Even so, the hemisphere not really symmetry as the EMC tend to accumulate more on the left due to some errors in the simulation setup. Nevertheless, some modification needed on the base of geometry such as increase the height of border, 3 kg/m.s is possible to be used. The simulation results show the approximate volume of EMC required for the encapsulation process was 6.03x10^-9 m³.

![Comparison between the simulation and experimental results](image)

**Figure 5. Comparison between the simulation and experimental results**

| Viscosity (kg/m.s) | Fluid Stress | Maximum Stress (MPa) | Minimum Stress (MPa) |
|-------------------|--------------|----------------------|---------------------|
| 3                 | ![Image](image) | 0.000899             | 0.000047            |
| 5                 | ![Image](image) | 0.00275              | 0.000026            |
| 6                 | ![Image](image) | 0.00404              | 0.000033            |

**Figure 6. Von Mises stress on the components**
Figure 6 shows the Von Mises stress on the LED and the wire bond. The stress given by each types of viscosities were different as the viscosity is linearly proportional to stress. The maximum stress increasing with the increasing of viscosity same goes to minimum stress. The Maximum stress are 0.000899 MPa, 0.00275 MPa and 0.00404 MPa, respectively. Tensile strength of the gold wire with diameter of 18 to 50 µm are between the range of 3.0 to 4.7 MPa, and sometimes the tensile strength of the gold wire can exceed 7 MPa due to the purity of the material\[15\]. The previous study on the reliability of gold wire bonding shows that gold wire bonding is capable of withstanding maximum stresses of 140.2 MPa at a temperature of 125°C and 191.4 MPa at the temperature of -40°C \[14\]. Hence, the Von Mises stress given by the fluid relatively is low and did not contribute significantly to the failure of the LED. Other factors such as temperature and others influenced more to failure in LED compared to stress given by the EMC during the encapsulation process.

4. Conclusion
The simulation of the encapsulation process is successfully done by utilizing the FSI technique. Modelling the chip and wire bonding size was based on the actual data found as stated LED chip size is 1mm x 1mm, and wire bonding size is 19.8µm. Next, the methods illustrated the encapsulation process, and others parameter was constant except the viscosity of the encapsulant. As a result, encapsulant viscosity suitable for the process is in range of 5 to 6 kg/m.s since the final structure of EMC tend to be more accurate. The encapsulant covered surface diameter for low viscosity model tend to be larger than the required diameter, which is 4mm. Hence, it supports the finding that viscosity of 3 kg / m.s is insufficient for the process. Then, the static structural simulation was carried out to determine the stress exerted by the encapsulant on the LED chip and wire bonding. The maximum and minimum Von Mises stress exerted by the encapsulant on the component was concluded from the finding. The stress of the encapsulant is significantly small and does not make enough contribution to the wire bonding failure.

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