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Investigating on the Effects of LED Design on Microvoids Formation

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DECLARATION

I declare that this thesis entitled "Investigating on the Effects of LED Design on Microvoids Formation" is the result of my own research except as cited in the references.

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Investigating on the Effects of LED Design on Microvoids Formation

ABSTRACT

This study meticulously investigates how LED design parameters intricately influence microvoids formation during the encapsulation process. Through the integration of innovative computational methods and rigorous experimental validation, the research comprehensively analyzes various factors, encompassing chip size. Employing advanced Simulation techniques such as Computational Fluid Dynamics (CFD) and SolidWorks CAD for precise modeling, the study accurately simulates the intricate processes involved in LED encapsulation. Simultaneously, practical experiments faithfully replicate real-world conditions, fortifying the study's findings with robust empirical evidence. The objective is to unravel the intricate relationship between LED design nuances and the incidence of microvoids, with the overarching goal of providing invaluable insights to refine and optimize LED encapsulation techniques. By meticulously exploring the multifaceted factors that influence microvoids formation, this research endeavors to significantly enhance LED reliability and performance. The combined use of simulation and experimentation offers a holistic understanding of LED packaging dynamics. Furthermore, these findings are poised to revolutionize solid-state lighting technology, offering practical applications that will steer advancements in LED design and manufacturing processes.

Keywords: LED design parameters, microvoids formation, computational methods, chip size influence, simulation techniques, SolidWorks CAD, Computational Fluid Dynamics (CFD), LED encapsulation modeling, real-world condition replication

Penyelidikan Tentang Kesan Reka Bentuk Led Ke Atas Pembentukan Mikrovoid

ABSTRAK

Kajian ini dengan teliti menyiasat bagaimana parameter reka bentuk LED mempengaruhi pembentukan mikrovoid semasa proses pengekapsulan. Melalui integrasi kaedah komputasi terkini dan validasi eksperimen yang teliti, penyelidikan ini menganalisis secara menyeluruh pelbagai faktor, termasuk saiz cip. Dengan menggunakan teknik Simulasi canggih seperti Dinamik Bendalir Komputasi (CFD) dan SolidWorks CAD untuk pemodelan yang tepat, kajian ini mensimulasikan dengan tepat proses rumit yang terlibat dalam pengekapsulan LED. Pada masa yang sama, eksperimen praktikal dengan setia meniru keadaan dunia nyata, mengukuhkan penemuan kajian dengan bukti empirikal yang kukuh. Objektifnya adalah untuk mengungkap hubungan rumit antara nuansa reka bentuk LED dan kejadian mikrovoid, dengan matlamat besar memberikan pandangan berharga untuk menyempurnakan dan mengoptimumkan teknik pengekapsulan LED. Dengan menyelidiki dengan teliti faktor-faktor berbilang yang mempengaruhi pembentukan mikrovoid, penyelidikan ini berusaha untuk meningkatkan secara signifikan kebolehpercayaan dan prestasi LED. Penggunaan bersama simulasi dan eksperimen menawarkan pemahaman holistik mengenai dinamik pembungkusan LED. Selain itu, penemuan ini bersedia untuk merevolusikan teknologi pencahayaan pepejal, menawarkan aplikasi praktikal yang akan mengemudikan kemajuan dalam reka bentuk LED dan proses pembuatan.

Kata Kunci: Parameter reka bentuk LED, pembentukan mikrovoid, kaedah komputasi, pengaruh saiz cip, teknik simulasi, SolidWorks CAD, Dinamik Bendalir Komputasi (CFD), pemodelan pengekapsulan LED, replikasi keadaan dunia nyata.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

LEDs	Light-Emitting Diodes
EMC	Epoxy Molding Compound
CAD	Computer-Aided Design
CFD	Computational Fluid Dynamics
VOF	Volume of Fluid
ISO	International Organization for Standardization
ANSYS	An engineering simulation software
GaAs	Gallium Arsenide
GaN	Gallium Nitride

LIST OF SYMBOLS

p	p-type semiconductor layer
n	n-type semiconductor layer
I	Electric current
V	Voltage
T	Temperature
µ	Microvoids
η	Viscosity
ρ	Density
σ	Surface Tension
ε	Electric Permittivity
∂	Partial derivative
∇	Del operator

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Light-Emitting Diodes (LEDs) transformed the world of illumination, becoming an indispensable aspect of modern electrical equipment and devices(Pode, 2020). Among the diverse solid-state lighting technologies, Light-Emitting Diodes (LEDs) emerged as one of the most prevalent and versatile options. LEDs found widespread applications, ranging from small electronic devices like smartphones to large-scale advertising billboards. They played a pivotal role in devices that displayed time, data, and information, and their efficiency, durability, and versatility contributed significantly to their widespread adoption.

An LED functioned as a semiconductor device that generated light when an electric current passed through it. This process involved the recombination of electrons with holes, leading to the emission of light. LEDs efficiently facilitate the flow of current in the forward direction while blocking it in the reverse direction, ensuring optimal light emission(Sain et al., 2020). These devices were constructed using heavily doped p-n junctions. The emitted light's color was determined by the semiconductor material and the level of doping, resulting in specific spectral wavelengths when forward biased.

To ensure the optimal performance and longevity of LEDs, the encapsulation process played a crucial role(Alim et al., 2021). One of the primary purposes of encapsulation was to protect the delicate semiconductor components from various environmental factors, such as moisture, dust, and mechanical damage(Ardebili et al., 2018). Additionally, encapsulation helped to enhance the LED's reliability by preventing corrosion and electrical short circuits. Epoxy Molding Compound (EMC) had become the material of choice for encapsulating LEDs due to its excellent protective properties and ability to form a robust and durable protective layer around the LED chip(Yazdan Mehr et al., 2020).

The encapsulation with EMC not only shielded the LED from harmful substances but also aided in thermal management(Tong, 2011). It efficiently dissipated heat generated during the LED operation, thereby improving its overall performance and reliability. Despite the numerous advantages of encapsulation, certain challenges could arise, affecting the LED's mechanical stability and thermal conductivity. One significant concern was the presence of defects like microvoids, which were small air bubbles trapped in the encapsulation material during the dispensing process.

The dispensing process was a crucial step in LED manufacturing and was part of the encapsulation process. It involved the uniform application of epoxy resin or other materials onto the LED die using specialized dispensing equipment. This step was vital in encapsulating the LED chip efficiently and precisely. The dispensing equipment ensured accurate and controlled dispensing of the epoxy resin, which was critical for achieving consistent results and reliable LED performance(Alim et al., 2021).

The formation of microvoids during the encapsulation and dispensing process could lead to reduced mechanical strength and integrity of the encapsulated LED package(Park et al., 2012). Moreover, these microvoids acted as thermal insulators, hindering the efficient dissipation of heat generated during LED operation, which could impact the LED's performance and longevity.

1.2 Problem Statement

The encapsulation process was a critical step in LED manufacturing, as it provided protection to the delicate semiconductor components from environmental factors and ensured the LED's reliability and longevity(Alim et al., 2021). Epoxy Molding Compound (EMC) was commonly used for encapsulating LEDs due to its protective properties and ability to create a robust protective layer. However, during the encapsulation process, certain challenges arose, particularly the formation of microvoids. Microvoids were small air bubbles that became trapped in the EMC during the dispensing process(Ishak et al., 2016). These microvoids could negatively impact the mechanical stability and thermal conductivity of the encapsulated LED package(Depaifve et al., 2020). Furthermore, they acted as thermal insulators, hindering the efficient dissipation of heat generated during LED operation. The presence of microvoids could lead to reduced LED performance, compromised reliability, and shortened lifespan, which was undesirable for various LED applications. Understanding the factors that influenced the formation of microvoids and their correlation with different LED design parameters was crucial to enhance LED encapsulation techniques and improve LED performance. However, the specific relationship between LED design and microvoids formation remained underexplored.

Therefore, the main problem addressed was to investigate the effects of LED design on the formation of microvoids during the LED dispensing process. By conducting experiments and simulations, this research aimed to identify the key LED design parameters that contributed to microvoids formation and quantify their impact on LED performance and reliability.

1.3 Objectives

I. To investigate the formation of microvoids in different LED design encapsulation, using computational method.
II. To verify the LED encapsulation in experimental and simulation

1.4 Scope of Study

This study focused on investigating the effects of LED design on microvoids formation during the LED dispensing process. Different LED designs were analyzed to understand their influence on microvoids. The research involved collecting and analyzing data, encompassing various LED design parameters, including LED structure, chip size, encapsulation material properties, dispensing speed, curing time, and environmental conditions. Additionally, the study utilized ANSYS software to simulate the LED dispensing process and analyzed the formation and distribution patterns of microvoids within the encapsulation material.

The scope of this study was limited to exploring microvoids specifically within the context of LED encapsulation and the dispensing process. While other factors might have affected LED performance and reliability, this thesis concentrated on understanding the relationship between LED design parameters and microvoids formation. The insights gained from this research would be valuable for LED manufacturers and researchers seeking to optimize LED encapsulation processes, thereby minimizing microvoids formation and improving LED reliability and performance. Furthermore, the findings could contribute to advancements in solid-state lighting technology, leading to the development of more efficient and reliable LED devices for various applications.

1.5 Significance of Study

The findings of this study held significant importance in understanding the impact of LED design on microvoids formation during the LED dispensing process. The results that were obtained:

I. Facilitated LED Manufacturers and Researchers in Optimizing LED Encapsulation Processes. By gaining insights into the influence of diverse LED design parameters on microvoids formation, this study empowered LED manufacturers to optimize their encapsulation processes effectively. This optimization endeavor aimed to curtail microvoids, thereby bolstering the mechanical stability, thermal conductivity, and overall reliability of the encapsulated LEDs.

II. The knowledge of this study could be used to enhance LED Performance and Lifespan. Leveraging the knowledge gained from this study, minimizing microvoids emerged as a viable approach to elevate LED performance and extend its lifespan. LEDs exhibiting fewer microvoids were anticipated to manifest superior thermal management capabilities, culminating in the creation of more efficient and long-lasting devices.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This chapter presented a comprehensive literature review on Light-Emitting Diodes (LEDs) encapsulation techniques, with a specific focus on the formation and impact of microvoids within the encapsulation material. The review covered essential topics, including LED fundamentals, various LED encapsulation methods, the LED dispensing process, the use of Epoxy Molding Compound (EMC) for encapsulation, the significance of microvoids formation, and the role of computational tools.

2.2 Light-Emitting Diodes (LEDs)

Light Emitting Diodes (LEDs) constitute semiconductor devices that convert electrical energy into light. Originally developed in the 1960s, LEDs have evolved as crucial components in modern electronics due to their efficiency and durability. Light-Emitting Diodes were compact electronic devices that emitted light when an electric current passed through them (Song et al., 2020). An LED functions as an optical semiconductor tool that transforms electrical energy into light energy when voltage is applied. When it's in a forward bias state, the recombination of electrons in the conduction band with holes in the valence band leads to the emission of light energy, a process known as electroluminescence. Unlike conventional p-n junction diodes allowing current flow only in the forward bias, LEDs function solely under forward bias conditions. This procedure involves linking the negative terminal of the battery to the n-type material and the positive terminal to the p-type material, thereby establishing a negative charge on the n-type material and a positive charge on the p-type material. While resembling a regular p-n junction diode in structure, LEDs utilize materials like gallium, phosphorus, and arsenic rather than the more traditional silicon or germanium. These elements and compounds contribute to the specific properties that enable light emission in LED technology. This deviation arises from the inability of silicon or germanium diodes to emit light; they primarily dissipate energy as heat, rendering them unsuitable for LED construction due to the absence of the desired light emission.

Light Emitting Diodes (LEDs) operate exclusively under forward bias conditions, where free electrons from the n-side and holes from the p-side are driven toward the junction. This biasing initiates a process of recombination in the depletion region and the semiconductor material itself. Figure 2.1 show Electron-Hole Recombination Process in an LED, in recombination process, free electrons in the conduction band combine with holes in the valence band, reducing the width of the depletion region. As charge carriers from both sides cross the p-n junction, some recombine within the depletion region, while others traverse the junction before recombining. The significant aspect is the emission of light during the recombination of free electrons with holes. In traditional silicon and germanium diodes, most of the energy is dissipated as heat, resulting in minimal light emission. However, materials like gallium arsenide and gallium phosphide, common in LED construction, produce photons with sufficient energy to generate intense visible light. The emission of light is intricately tied to the energy levels of valence and free electrons, forming the valence and conduction bands, respectively. When valence electrons gain energy, they can generate free electrons and holes, which subsequently undergo recombination. The emitted light's intensity depends on the material properties, specifically the forbidden gap or energy gap between the conduction and valence bands. In LEDs, the large forbidden gap ensures that free electrons possess higher energy, leading to the release of high-energy photons. This contrasts with normal silicon diodes, where low-energy photons are emitted due to a smaller energy gap, rendering them invisible. LED efficiency is influenced by injected current and temperature. Increased current and lower temperatures enhance the generation of light. LEDs exclusively operate under forward bias, as reverse bias conditions lead to the movement of majority carriers away from the junction, inhibiting recombination and light emission. Extreme reverse bias voltages can even damage the LED. Figure 2.2 displayed the symbol of Light-Emitting Diodes (LEDs), which was the standard diode symbol with the addition of two small arrows denoting light emission.

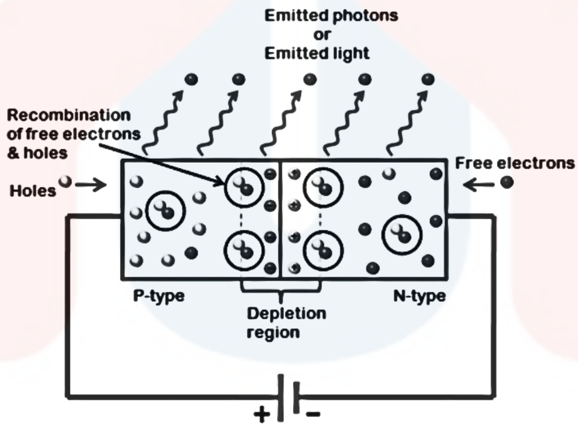


Figure 2.1 : Electron-Hole Recombination Process in an LED

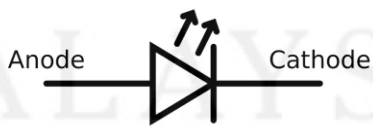


Figure 2.2 : The Light-Emitting Diodes (LEDs) symbol.

LED construction involves depositing three distinct semiconductor layers on a substrate, Figure 2.3 shows the layer of Light-Emitting Diodes (LEDs), n-type semiconductor, p-type semiconductor, and the active region situated between them. In a forward-biased LED, electrons from the n-type semiconductor and holes from the p-type semiconductor migrate towards the active region. Most charge carriers, when they recombine within the active region (or depletion region), emit visible or invisible light. This phenomenon predominantly occurs in the depletion region, leading to the emission of light from the LED. Essentially, the depletion region serves as the primary source of light emission in an LED.

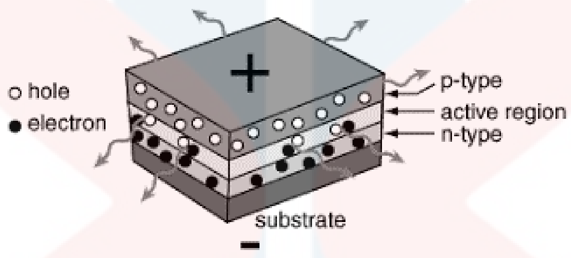


Figure 2.3 : The layer of Light-Emitting Diodes (LEDs).

In an LED, each layer—like the p-type semiconductor, n-type semiconductor, and the depletion region—serves a critical function. P-type semiconductors are crafted by introducing trivalent impurities to an intrinsic semiconductor, where this layer is primarily composed of holes as the primary charge carriers. Within this layer, electric current is predominantly carried by holes. On the other hand, the n-type semiconductor is generated by introducing pentavalent impurities to an intrinsic semiconductor, and it mainly consists of free electrons as the primary charge carriers. Free electrons primarily conduct electric current in this layer. The depletion region is situated between the p-type and n-type semiconductors, the depletion region lacks mobile charge carriers like free electrons or holes. It acts as a barrier to electric current flow, opposing the movement of electrons from the n-type semiconductor and holes from the p-type semiconductor. Overcoming this barrier requires applying a voltage higher than the depletion layer's barrier potential to initiate electric current flow.

LEDs were meticulously constructed using semiconductor materials, such as gallium arsenide (GaAs) or gallium nitride (GaN) (Gaffuri et al., 2021), with the semiconductor layers carefully arranged between two electrodes. The advantages of LEDs were manifold, encompassing high energy efficiency, an extended operational life, minimal heat generation, and the capacity to adjust brightness levels. Their diversity in colors and sizes further amplified their versatility for a wide array of applications. These applications ranged from lighting solutions to displays, including LED monitors and TVs, which provided enhanced visual experiences. In signaling systems, such as traffic lights, LEDs delivered efficient and reliable signaling. Within electronic devices, they functioned as indicators, conveying essential information with precision.

2.3 LED Encapsulation Techniques

LED encapsulation ensured LED longevity, performance, and reliability. Materials like epoxy, silicone, and others shielded internal components. These materials possessed distinct properties tailored for specific applications. Figure 2.4 displayed the typical LED Encapsulation Structure.

The process of LED encapsulation involved multiple layers, encompassing a transparent epoxy or silicone primary layer that safeguarded the LED chip, wire bonds, and internal components from the detrimental effects of moisture, dust, and mechanical stress. Typically, a lens or cover was positioned above, directing light, and providing supplementary protection. This structural configuration upheld LED efficiency under diverse conditions.

The encapsulation effectively acted as a barrier, shielding LEDs from a gamut of external threats. Moisture, for instance, led to corrosion and premature failure, dust diminished light emission, and mechanical stress could impair electrical and optical properties. Through its efficacy, encapsulation countered these risks, significantly extending the LED's operational lifespan.

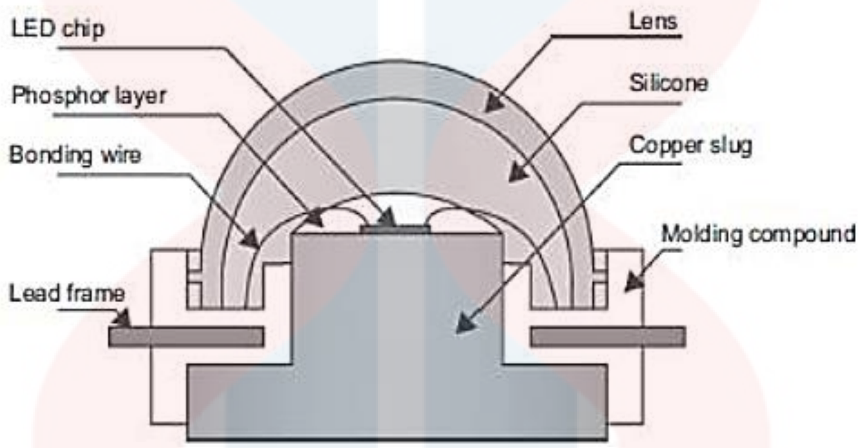


Figure 2.4 : Typical LED Encapsulation Structure (Roslan et al., 2020)

2.3.1 LED Dispensing Process

A pivotal stage in LED encapsulation is the dispensing process, wherein the encapsulant material was meticulously applied to the LED components. Figure 2.5 depicted the Light-Emitting Diodes (LEDs) dispensing process. This process entailed the precise deposition of encapsulant material onto the LED chip and its surrounding elements.

Dispensing played a crucial role in ensuring the comprehensive coverage of the LED chip, effectively filling the gap between the chip and the lens(Annaniah et al., 2023). This meticulous application sealed the package, preventing the infiltration of contaminants.

The accuracy of the dispensing process wielded a substantial influence on the overall performance and reliability of the LED. Notably, advancements in dispensing technology, including the integration of automated systems and precision control mechanisms, contributed to elevated encapsulation outcomes and consistent LED performance.

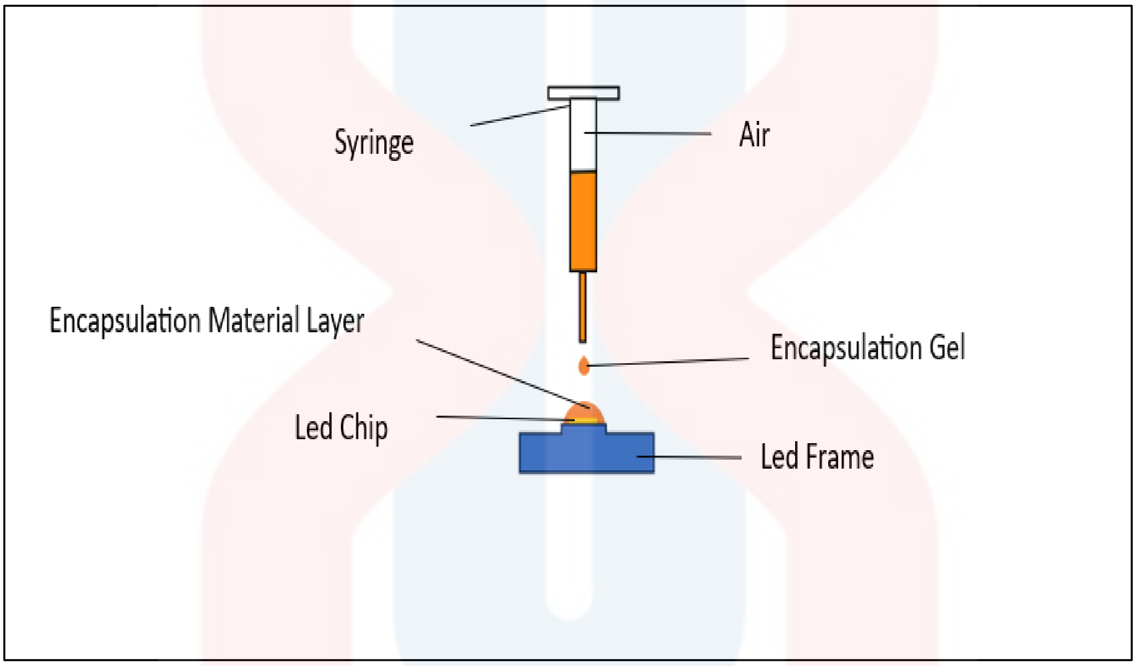


Figure 2.5 : LED Dispensing Process Setup

2.4 Epoxy Molding Compound (EMC)

Epoxy Molding Compound (EMC), synonymous with epoxide resin, has emerged as a preferred material in polymer science, finding extensive applications in various industries. Characterized by the molecular formula $C_{28}H_{30}O_2$ and composed of compounds such as 1,4-Divinylbenzene (CID 66041), Styrene (CID 7501), and Benzyl glycidyl ether (CID 94247) (Information, 2021), EMC offers a unique blend of properties that contribute to its versatility. EMC's molecular weight of 398.5 g/mol reflects its intricate structure. With a hydrogen bond donor count of 0 and hydrogen bond acceptor count of 2, EMC exhibits intriguing molecular interactions. The presence of 7 rotatable bonds contributes to its dynamic nature, while the computed exact mass, monoisotopic mass, and topological polar surface area provide insights into its mass distribution and surface characteristics. Comprising 1,4-Divinylbenzene (CID 66041), Styrene (CID 7501), and Benzyl glycidyl ether (CID 94247), EMC's components play distinct roles in shaping its overall properties and behaviour. Epoxy Molding Compound (EMC) has gained prominence as a reliable choice for safeguarding Light-Emitting Diodes (LEDs). Studies (Zhao et al., 2015) have demonstrated its efficacy as a robust shield against environmental elements, ensuring consistent and long-lasting LED performance. EMC's exceptional thermal conductivity enhances its heat dissipation properties, contributing to the prolonged efficiency of LEDs. Moreover, its optical clarity plays a pivotal role in preserving luminous efficiency by enabling distortion-free transmission of light. The inherent strong adhesion properties of EMC have fostered the creation of a moisture and stress-resistant bond between LEDs and the compound. This robust bonding mechanism not only ensures the structural integrity of LEDs but also enhances their reliability in challenging environmental conditions.

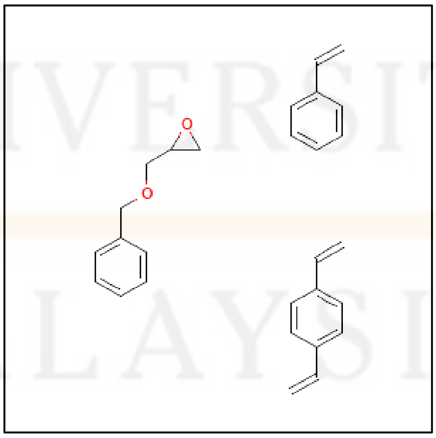


Figure 2.6 : The Formulation of Epoxy Molding Compounds (EMCs) (Information, 2021)

2.5 Microvoids Formation and its Impact

Microvoids, minute air pockets or voids discovered within the encapsulation material of Light-Emitting Diodes (LEDs), assumed a pivotal role in LED encapsulation(Li et al., 2015). Their presence held remarkable significance, as they exerted considerable influence. The genesis of these microvoids was governed by a synergy of intrinsic and extrinsic factors during the LED encapsulation process. Inherent factors encompassed material attributes like viscosity, curing behavior, and thermal characteristics. The polymerization-driven curing process had the potential to entrain air, ultimately leading to the emergence of microvoids. External factors, including temperature, humidity, and atmospheric pressure, also exerted their influence. The coexistence of moisture and air pockets within the encapsulant material could serve as triggers for the formation of microvoids. Figure 2.6 visually depicted the manifestation of microvoids within Epoxy resin.

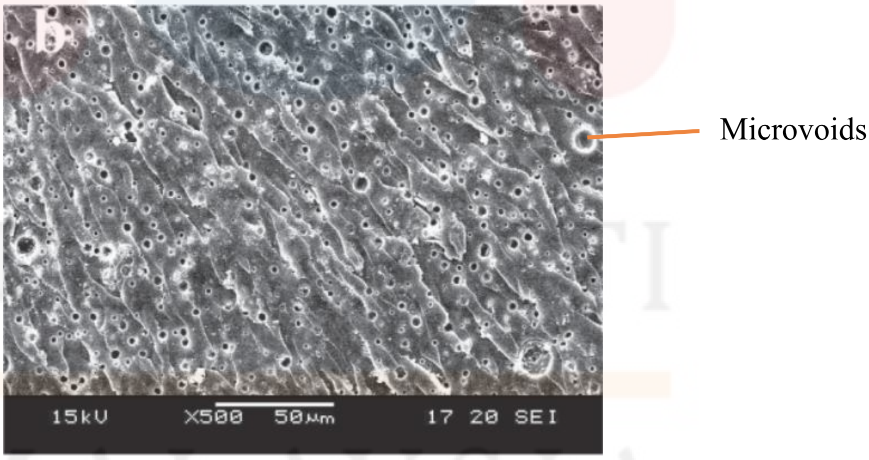


Figure 2.7 : The Microvoids of Epoxy resin (Gonçalez et al., 2006)

The implications of these microvoids extended significantly to the performance and reliability of LED devices(Cai et al., 2016). One of the primary consequences entailed a reduction in thermal conductivity. Functioning as insulating barriers, these microvoids impeded the efficient dissipation of heat emanating from the LED chip. The resultant thermal impedance had the potential to elevate operating temperatures, thereby impacting the lifespan and stability of LED performance. Furthermore, the presence of microvoids led to alterations in the refractive indices within the encapsulant. This phenomenon induced light scattering and consequently modified emission patterns. So, it had a detrimental effect on the luminous efficiency and uniformity of light, qualities that held particular importance in applications necessitating consistent, high-quality illumination.

2.6 Influence of LED Design on Microvoids

The intricate relationship between LED design and the formation of microvoids within encapsulation materials has been systematically investigated, with a focus on manipulating key variables to discern their effects. Recent studies (Li et al., 2022) highlight the pivotal role of LED component layout, where arrangements of LED chips, bonding wires, and lens interfaces play a significant role in microvoids formation. In a systematic investigation, key variables such as the LED chip angle, the number of LED chips, and the size of the LED chip have been manipulated to discern their impact on microvoids. The configuration of LED chips, bonding wires, and lens interfaces has been identified as influencing factors. Specific LED design parameters, including chip angle, significantly affect microvoids occurrence. The entrapment of air during encapsulation, as observed by (Tan & Singh, 2022) is notably influenced by the number of LED chips and their arrangement. The systematic manipulation of the number of LED chips has provided insights into how air entrapment can be controlled during the encapsulation process, consequently affecting microvoids formation. Moreover, the size of the LED chip has been a crucial parameter in this investigation. Uneven material distribution and localized microvoids have been attributed to specific design geometries influenced by the size of the LED chip. Mechanical stresses induced by chip positioning and lens attachment, along with thermal management strategies within LED design, have demonstrated direct effects on microvoids formation. Higher chip temperatures, resulting from design choices, have been correlated with increased microvoids creation due to heightened air and moisture volatility. Conversely, the integration of effective thermal pathways and heat dissipation mechanisms into LED design has shown promise in mitigating thermal stress, curbing microvoids formation, and boosting overall LED reliability. The optics design, encompassing lenses and diffusers, further compounds the influence on microvoids distribution. Non-uniform lens shapes hinder the even distribution of encapsulant material, leading to variations in thickness and the emergence of microvoids.

2.7 Computer-Aided Design (CAD) in LED Applications

The integration of SolidWorks, a versatile CAD software(Arora et al., 2022), empowered LED designers to craft intricate and precise LED structures. Leveraging its intuitive interface and parametric design capabilities, designers gained the ability to visualize and modify LED components with ease. The precision extended to LED package layouts, chip positioning, and encapsulant interfaces, meticulously modelled and optimized within SolidWorks. This approach assured an accurate representation of physical attributes in the virtual realm.

2.8 Computational Fluid Dynamics (CFD)

Computational Fluid Dynamics (CFD) played a vital role in understanding the complex mechanisms that governed the formation of microvoids. Through numerical solutions of fluid dynamics equations, CFD simulations analyzed the behavior of encapsulant materials during

LED encapsulation. The Volume of Fluid (VOF) method within CFD was crucial, accurately tracking fluid interfaces. VOF is a part of the Eulerian class of methods, functioned as an advection scheme that traced evolving interfaces. It worked alongside flow-solving algorithms, such as the Navier-Stokes equations for fluid motion(Mulbah et al., 2022). The adoption of CFD with the VOF method provided insights into fluid flow patterns and material distribution. By visualizing the interaction of encapsulant material with the LED structure, simulations identified regions prone to the formation of microvoids due to uneven material distribution.

2.9 Summary

This comprehensive literature review has delved into various aspects of Light-Emitting Diodes (LEDs) encapsulation techniques, with a specific emphasis on understanding the formation and impact of microvoids within the encapsulation material. The review covered essential topics, starting with the fundamental principles of LEDs, encapsulation methods, the dispensing process, the use of Epoxy Molding Compound (EMC), the significance of microvoids formation, and the role of computational tools. The foundation of LED technology was explored, tracing its development since the 1960s, highlighting its unique electroluminescence process under forward bias conditions. The distinctive structure of LEDs, composed of semiconductor layers and a depletion region, was elucidated, emphasizing the importance of materials like gallium arsenide and gallium phosphide for efficient light emission. LED encapsulation techniques were outlined, emphasizing the protective role of materials such as epoxy and silicone in shielding internal components from environmental threats. The dispensing process was identified as a crucial step, ensuring comprehensive coverage of LED components, and contributing to enhanced reliability. Epoxy Molding Compound (EMC) emerged as a key material in LED encapsulation, offering properties such as exceptional thermal conductivity, optical clarity, and strong adhesion. Its role in safeguarding LEDs against environmental elements was highlighted, demonstrating its efficacy in ensuring consistent and long-lasting LED performance. The formation of microvoids within LED encapsulation was explored in detail, considering both intrinsic and extrinsic factors that contribute to their emergence. The implications of microvoids on LED performance, particularly in terms of thermal conductivity and light emission, were discussed, underlining their significance in LED reliability. The influence of LED design on microvoids formation was systematically investigated, with a focus on key variables such as LED chip angle, the number of LED chips, and the size of the LED chip. The configuration of LED components and thermal management strategies were identified as crucial factors affecting microvoids occurrence. The integration of Computer-Aided Design (CAD) and Computational Fluid Dynamics (CFD) in LED applications was outlined, emphasizing their role in precise LED design and understanding the fluid dynamics governing microvoids formation. So, this literature review has provided a comprehensive understanding of LED encapsulation techniques, microvoids formation, and the intricate relationship between LED design and microvoids. The exploration of key variables, materials, and computational tools sets the stage for further investigations and advancements in the field of LED technology.

CHAPTER 3

METHODOLOGY

3.1 Research Flow

This study was conducted with a structured approach, covering stages like literature review, methodology formulation, simulation, experimentation, and results analysis. Figure 3.1 shows a research process in this study. Beginning with a literature review, existing studies on LED encapsulation, microvoids, and related design factors were explored. Based on these insights, a methodology involving simulation and experimentation was developed. Simulation modelled LED encapsulation under various conditions, validated by practical experiments. Simulation included accurate modelling, meshing for precise analysis, and real-world boundary conditions.

Material properties were integrated, and the Volume of Fluid (VOF) method was used to analyse microvoids. Experiments replicated encapsulation using real equipment, collecting data for validation. Comparing simulation and experimental results identified trends between LED design parameters and microvoids formation. The study concluded with comprehensive conclusions drawn from literature, simulation, and experimentation findings, contextualizing LED encapsulation, microvoids, and their relation to design parameters.

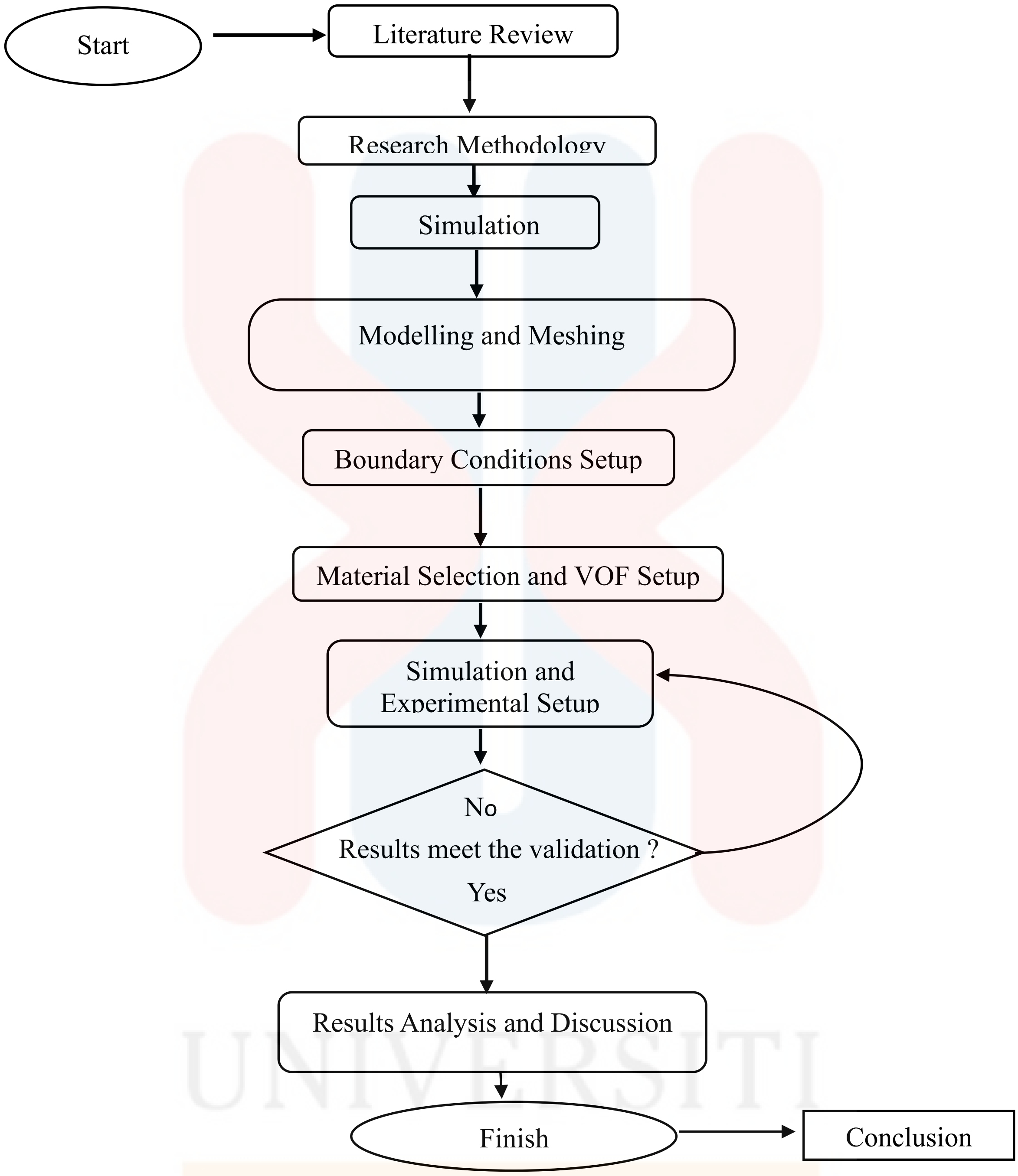


Figure 3.1 : Research Flow Chart

3.2 Materials

In the scope of this study, the selection of materials holds paramount significance to accurately emulate real-world conditions and investigate the encapsulation process and microvoids formation. The LED 5050 model, characterized by its dimensions of 5.0mm x 5.0mm, serves as the foundational nucleus of the experimental setup. Central to the experimental apparatus, the 3mm syringe assumes the role of the reservoir for the Epoxy Compound Molding (EMC) fluid.

Syringe needle is using Flat head Needle. this syringe needle is 18-gauge needle. This needle, securely affixed to the syringe, facilitates meticulous dispensation of the EMC fluid onto the LED 5050 model, ensuring an accurate representation of the encapsulation process.

Epoxy Compound Molding (EMC) is selected as the encapsulation material for the experimental and simulation studies. EMC offers a robust protective layer around the LED 5050 model due to its excellent protective properties and thermal conductivity. This non-Newtonian fluid exhibits constant viscosity with zero shear stress. Moreover, density, viscosity and surface tension of EMC is shown as in the Table 3.1.

Table 3.1 Material Properties of Epoxy Compound Molding (EMC)

Properties	**Epoxy Molding Compound**
Density (kg/m3)	1800
Viscosity (kg/m. s)	0.448
Surface Tension(N/m)	20

3.3 Methods

The LED model is meticulously crafted through modeling using SolidWorks® software, renowned for its advanced computer-aided design (CAD) capabilities. Adhering to the ISO-9001 standard ensures robustness and quality in the LED structure. This CAD software empowers accurate representation and modeling of complex LED components, enabling a faithful reproduction of the real-world structure. For the simulation phase, the LED model is further transformed into a computational model using ANSYS software. The meshing process is employed to discretize the geometry, ensuring precise representation. Boundary conditions are established to mirror the actual operating conditions as closely as possible. The Volume of Fluid (VOF) method is implemented within ANSYS software to simulate the fluid flow and interface tracking during the LED encapsulation process(Zubir et al., 2022). The software's VOF capabilities allow visualization of fluid behaviors, capturing the interaction of the encapsulant material with the LED structure. Parameters such as viscosity, surface tension, and density are defined for accurate simulation.

3.3.1 Modelling

The integration of Computational Fluid Dynamics (CFD) within Ansys Fluent, as highlighted by Ching & Abdullah (2022), aligns seamlessly with the SolidWorks-generated LED package model depicted in Figure 3.2. SolidWorks software serves as the foundation for creating an accurate virtual LED package, closely replicating the dimensions and features of the LED 5050 model, ensuring fidelity to the real-world LED structure. This comprehensive CAD software enables precise modelling and visualization, forming the basis for subsequent CFD simulations. The combination of CFD simulations and CAD modelling, as discussed by Ching & Abdullah (2022), provides a robust platform for understanding fluid dynamics, material interactions, and microvoids formation during the dispensing and encapsulation processes of Epoxy Molding Compound (EMC) onto the LED. Additionally, the meticulous construction of a 2D domain, encompassing components such as the needle head, air domain, LED substrate, and LED Chip, as illustrated in Figure 3.2, ensures a faithful representation for detailed analysis and simulation purposes (Ching & Abdullah, 2022).

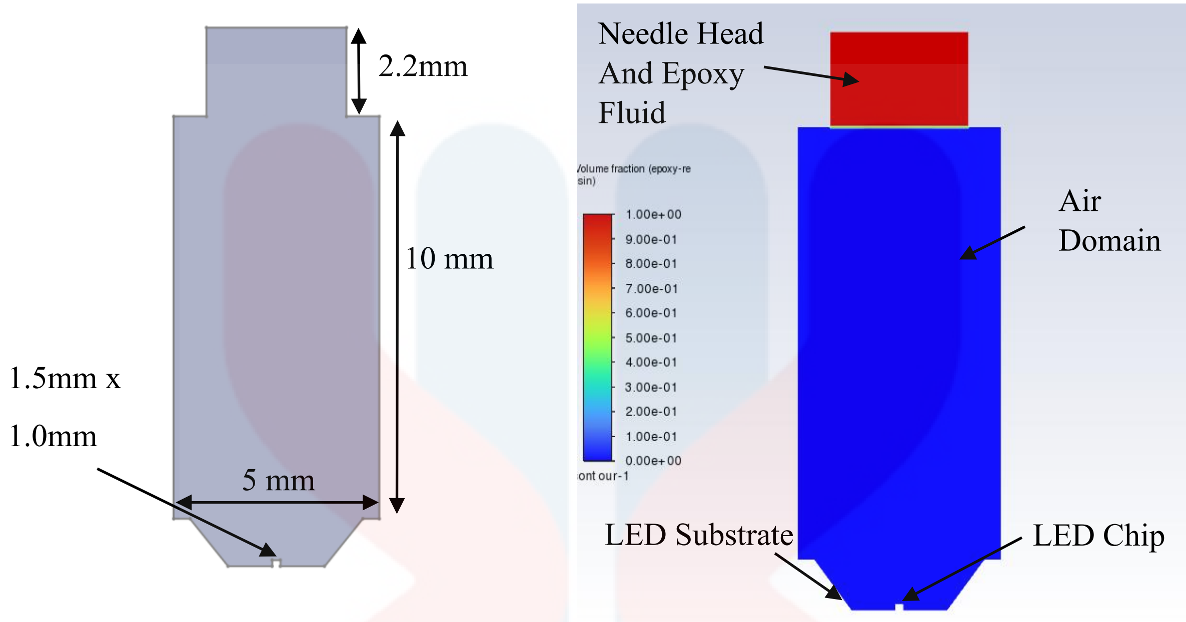


Figure 3.2 : Dimension and components LED 5050 Model in SolidWorks and Ansys

The seamless integration of the CAD model within SolidWorks and the subsequent CFD simulations carried out using Ansys Fluent yield a comprehensive and insightful understanding of the intricate fluid dynamics and encapsulation process. This synergistic approach is pivotal in unraveling the phenomenon of microvoids formation and plays a crucial role in the thorough analysis of LED performance within the encapsulation context.

3.3.2 Meshing and Boundary Conditions

Due to the pivotal role that the number of meshing elements plays in CFD simulations, we undertook an investigation into various element sizes. We considered five different mesh configurations denoted as Mesh 1, Mesh 2, Mesh 3, Mesh 4, and Mesh 5, corresponding to element sizes of 0.089 mm, 0.079mm, 0.050 mm, 0.049 mm, and 0.048 mm, respectively. The mesh quality across these five distinct element sizes is depicted in Figure 3.4.

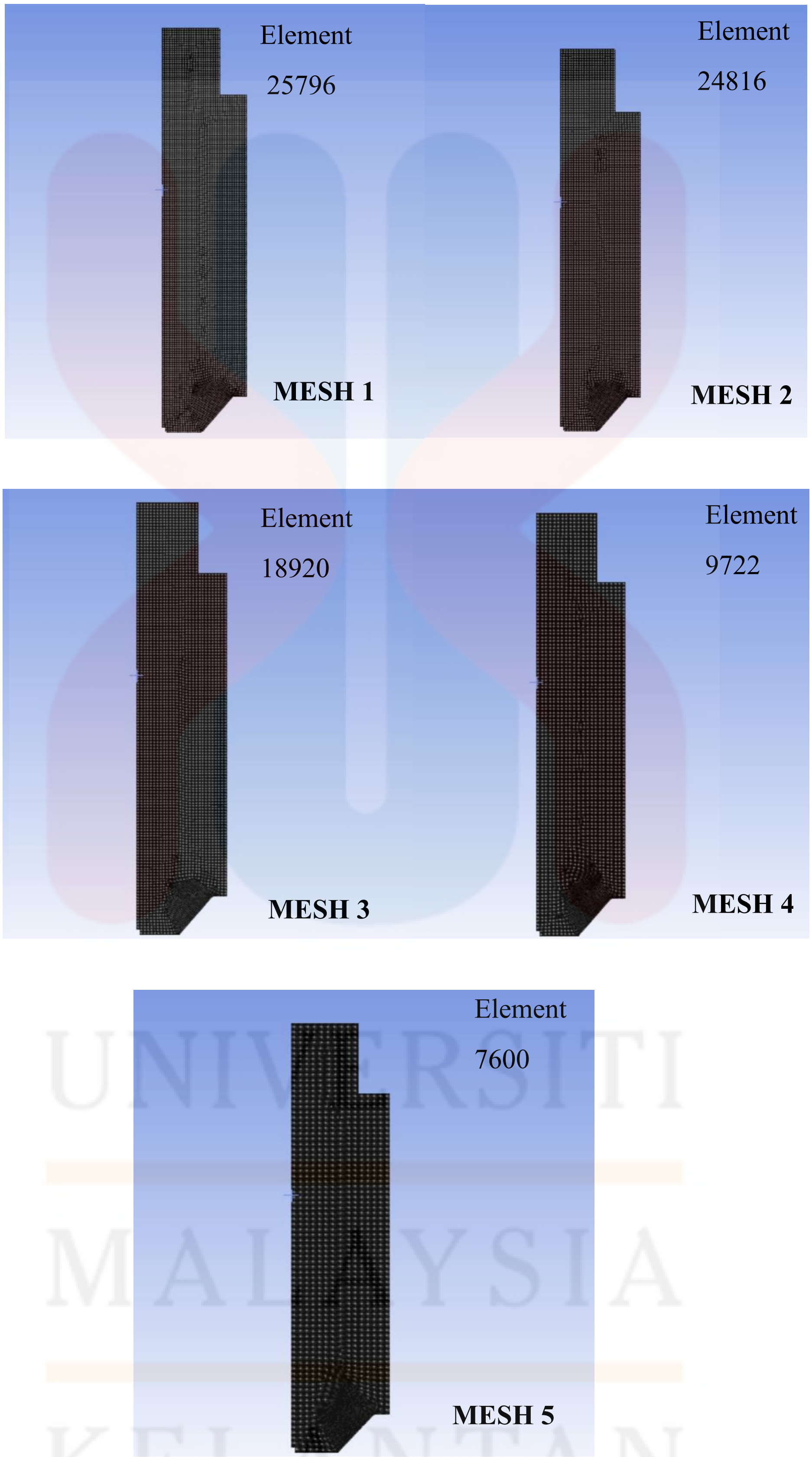


Figure 3.4 : Mesh illustration for five different elements sizes

3.3.3 Volume of Fluid (VOF) Setup

The Volume of Fluid (VOF) method, using an implicit multiphase VOF model, was employed for simulating the behavior of the Epoxy Molding Compound (EMC) during the LED encapsulation process(Ishak et al., 2019). In this simulation, the k-epsilon viscous model was chosen to characterize the fluid flow of EMC. Additionally, the effects of gravity were included in the simulation, with a gravitational acceleration of -9.81 m/s^2 applied in the negative y-direction to account for its influence on fluid behavior.

The materials involved in the simulation were defined based on the parameters outlined in Table 3.1. This ensured accurate representation of the fluid properties, such as density, viscosity, and surface tension, crucial for capturing the real-world behavior of EMC. The inlet contact angle was set at 90 degrees, determining the angle at which the EMC material met the LED model's surface. This parameter played a significant role in influencing the fluid dynamics and interaction between the EMC and the LED model.

The time step size for the entire simulation was set to 1e-06 seconds, ensuring accurate tracking of fluid interface movement and dynamics. A total of 6,000-time steps were employed throughout the simulation to capture the transient behavior of the encapsulation process comprehensively.

3.4 Governing Equation

In virtual modeling, the strategies utilized to simulate the LED encapsulation process were Volume of Fluid (VOF) and software tools like ANSYS Fluent. These methodologies played a pivotal role in analyzing the behavior of epoxy molding compound (EMC) as it was dispensed onto the LED substrate and interacted with the LED clips during the encapsulation process.

The movement of the epoxy molding compound (EMC) in the simulation was described using three-dimensional incompressible flow transport equations (utilizing ANSYS Fluent). These equations encompassed continuity (representing mass conservation), Navier-Stokes, Newtonian fluids, surface tension as outlined by (Khor & Abdullah, 2012):

The continuity equation (representing mass conservation) was formulated as follows:

Continuity Equation :

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

where u, v and w are velocities of the fluid that flow in x, y and z axis respectively.

The Navier-Stokes equation for x-direction can be illustrated as below:

$$\frac{\partial u}{\partial x} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z} = -\frac{1}{p}\frac{\partial p}{\partial x} + \left[\frac{\partial}{\partial x}\left(n\frac{\partial u}{\partial x}\right) + \frac{\partial}{\partial y}\left(n\frac{\partial u}{\partial y}\right) + \frac{\partial}{\partial z}\left(n\frac{\partial u}{\partial x}\right)\right] + g_x$$

For y and z directions:

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z} = -\frac{1}{p}\frac{\partial p}{\partial y} + \left[\frac{\partial}{\partial x}\left(n\frac{\partial v}{\partial x}\right) + \frac{\partial}{\partial y}\left(n\frac{\partial v}{\partial y}\right) + \frac{\partial}{\partial z}\left(n\frac{\partial v}{\partial z}\right)\right] + g_y$$

$$\frac{\partial w}{\partial t} + u\frac{\partial w}{\partial y} + v\frac{\partial w}{\partial z} + w\frac{\partial u}{\partial z} = -\frac{1}{p}\frac{\partial p}{\partial z} + \left[\frac{\partial}{\partial x}\left(n\frac{\partial w}{\partial x}\right) + \frac{\partial}{\partial y}\left(n\frac{\partial w}{\partial y}\right) + \frac{\partial}{\partial z}\left(n\frac{\partial w}{\partial z}\right)\right] + g_z$$

In the context of fluid dynamics, the equation set represents the fundamental Navier-Stokes equations governing fluid flow. These equations describe how various factors interplay within a fluid medium. The density (ρ) influences the mass of the fluid, while the velocity vectors (u, v, w) in the x, y, and z directions respectively, determine the fluid's motion. The static pressure (P) signifies the internal forces within the fluid. Time (t) serves as a parameter highlighting potential changes over temporal intervals. Viscosity (η) characterizes the fluid's resistance to deformation, impacting its flow behaviour. Additionally, the gravitational forces in each direction (gx, gy, gz) contribute to the overall dynamics, influencing the fluid's movement and pressure distribution within a given space. Together, these variables encapsulate the complex interactions governing fluid motion and behaviour within the Navier-Stokes equations, essential for analysing and predicting fluid flow in various scenarios. The EMC viscosity is assumed to be constant at no temperature. Hence, the Newtonian fluid equation can be defined as :

$$\eta = \frac{\tau}{y}$$

In the realm of fluid dynamics, the Newtonian fluid equation encapsulates the relationship between shear stress and shear rate within a fluid medium. Shear stress (τ) denotes the force per unit area experienced by the fluid due to the applied force or velocity gradient. The shear rate (y) signifies the rate of change of velocity as the fluid layers move or slide past each other. Dynamic viscosity (η) stands as a fundamental measure of the fluid's internal friction or resistance to flow. In a Newtonian fluid, this equation elegantly portrays that the shear stress is directly proportional to the shear rate, with the dynamic viscosity serving as the proportionality constant.

3.5 Experimental Setup

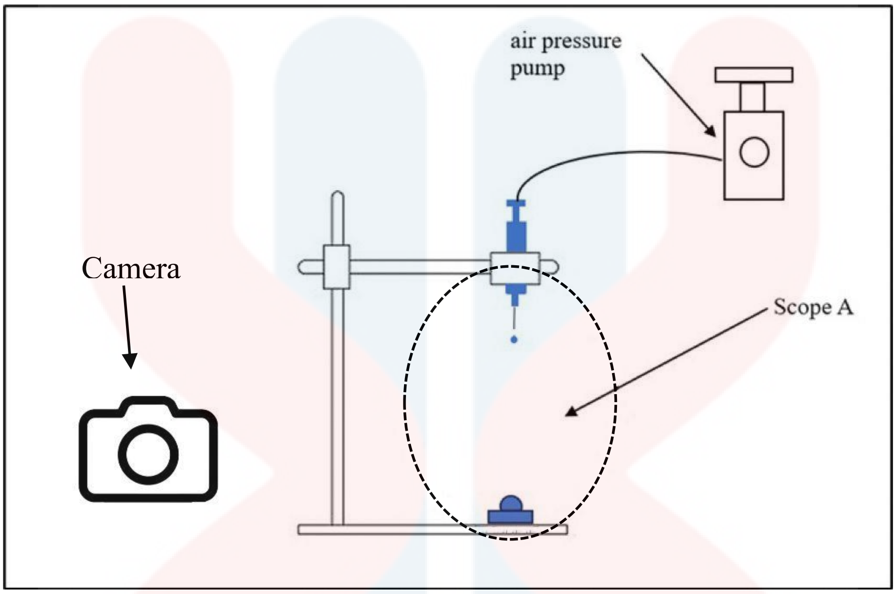


Figure 3.5 : Setup of experiment

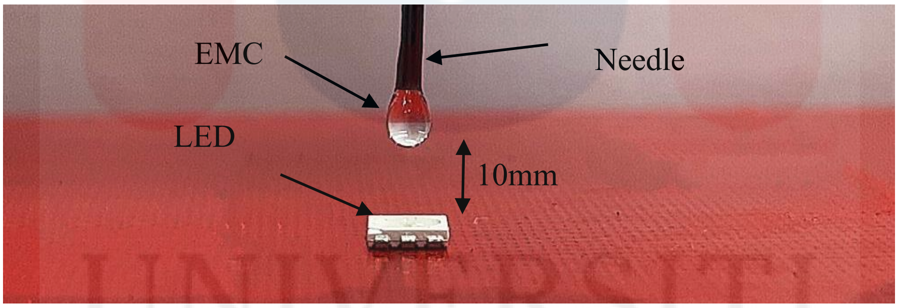


Figure 3.6 : Scope A dispensing process of LED

The experimental phase of this study aimed to validate and enhance the insights gained from simulation results by replicating the LED encapsulation process using practical equipment. The experimental setup was designed to closely mimic real-world conditions and involved a series of well-defined steps. At its core, the LED substrate, fashioned to resemble the LED 5050 model, formed the foundation for encapsulation and microvoids analysis.

Figures 3.5 and 3.6 show the setup of experiment and dispensing process of LED. The controlled dispensation of Epoxy Molding Compound (EMC) material onto the LED substrate was facilitated by a precise syringe dispenser equipped with a 3ML syringe and an 18-gauge flat-head needle. This process was complemented by an air pressure pump that ensured consistent and regulated material deposition. The carefully prepared EMC material, adhering to properties specified in Table 3.1, was applied to simulate encapsulation.

The analysis of microvoids was conducted using ANSYS simulation software, enabling the visualization and characterization of the encapsulated regions. This comprehensive experimental approach, executed with attention to detail and accuracy, provided empirical validation and practical insights into the intricate dynamics of microvoids formation within the context of LED encapsulation.

3.6 Parametric Study

In this parametric study, a systematic investigation is employed to manipulate key variables, specifically the LED chip angle, the number of LED chips, and the size of the LED chip. This deliberate variation spans a range of LED chip angles 0.7°, 0.65°, 0.8°, 0.95°, 0.5°, LED chip quantities 3, 5, 7, 9, 11, and diverse LED chip sizes 0.4 x 0.35, 0.30 x 0.25, 0.20 x 0.15, 0.25 x 0.20, 0.35 x 0.30. The primary objective is to unveil the intricate interplay between these parameters and their consequential effects on pressure and velocity trends during the LED encapsulation process. This nuanced exploration aims to reveal how alterations in the LED chip angle, the quantity of LED chips, and the dimensions of the LED chip influence the original pressure and velocity dynamics. The investigation seeks to determine whether changes in these parameters lead to an increase or decrease in pressure and velocity during encapsulation. Beyond these primary variables, the scrutiny extends to examine their potential influence on microvoids formation.

The guiding question of the study is whether shifts in pressure and velocity correlate with discernible changes in microvoids formation. Specifically, the objective is to ascertain whether adjustments in the LED chip angle, the number of LED chips, and the size of the LED chip result in variations in the occurrence, magnitude, or size of microvoids within the encapsulated structure. This comprehensive analysis within the established simulation framework aims to provide a thorough understanding of the intricate relationships between the selected parameters and the multifaceted dynamics of microvoids formation.

3.7 Summary

In summary, this study utilized a structured methodology encompassing literature review, simulation, and experimentation to delve into the intricate dynamics of LED encapsulation and microvoids formation. The simulation, conducted with SolidWorks and ANSYS software, allowed for precise modeling and analysis of fluid flow using the Volume of Fluid (VOF) method. The experimental setup mirrored real-world conditions and validated simulation results. A parametric study systematically manipulated key variables, revealing discernible impacts on pressure, velocity dynamics, and microvoids formation during LED encapsulation. The synthesis of findings contributes a nuanced understanding of the interplay between LED design parameters and microvoids. This research provides valuable insights for optimizing LED encapsulation processes and opens avenues for further exploration in advanced materials and innovative encapsulation techniques to enhance LED performance and reliability.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Overview

In this chapter, the outcomes of comprehensive investigations into the influence of LED design on microvoids formation during the LED encapsulation process are presented. The Grid Dependency Test is discussed, outlining the meticulous selection of an appropriate mesh for simulation purposes. A critical comparison between simulation and experimental results is provided through the Simulation Vs Experimental analysis, establishing the reliability and accuracy of the simulation model. The Parametric Study delves into the effects of various LED design parameters on microvoids formation, shedding light on the intricate relationships between these factors. Furthermore, the influence of LED chip shape and size is scrutinized as a crucial aspect of the encapsulation process. This chapter serves as a pivotal exploration of the interplay between design variables and microvoids formation, offering valuable insights into optimizing LED encapsulation procedures.

4.2 The Grid Dependency Test

Quality mesh plays a vital role in enabling the computational fluid dynamics (CFD) solver to produce accurate solutions while optimizing processing resources. Mesh independence is a technique employed to determine the ideal number of meshing elements and cells required to achieve a particular convergence value. Its aim is to minimize computational costs without compromising solution accuracy(Chirica et al., 2019).

To determine the most suitable mesh element size for the simulation analysis, five models were assessed, each with varying element sizes: Mesh-1 (0.048 mm), Mesh-2 (0.049 mm), Mesh-3 (0.50 mm), Mesh-4 (0.079 mm), and Mesh-5 (0.089 mm).

The evaluation of pressure applied to the LED chip by EMC serves as the foundation for performing grid-independent tests across a range of mesh sizes, as depicted in Figure 4.1. Table 4.1 presents the statistics of mesh elements and pressure for each model utilized in the grid independence test.

Table 4.1 : Statistics of Mesh Elements and Computational Time (hours)

Mesh Type	**Nodes**	**Elements**	**Computational Time (hours)**	**Pressure (MPa)**
Mesh-1 (0.048 mm)	26418	25796	12	0.0000226
Mesh-2 (0.049 mm)	25432	24816	9	0.0000228
Mesh-3 (0.050 mm)	20400	18920	6	0.0000088
Mesh-4 (0.079 mm)	10098	9722	3	0.0000011
Mesh-5 (0.089 mm)	7944	7600	0	0

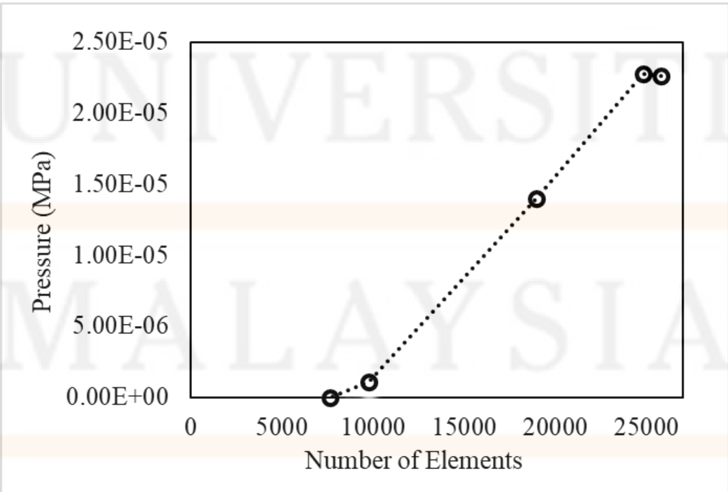


Figure 4.1: Pressure (MPa) measurement against Number of Elements

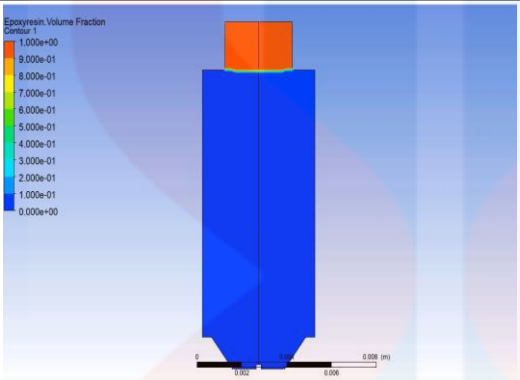
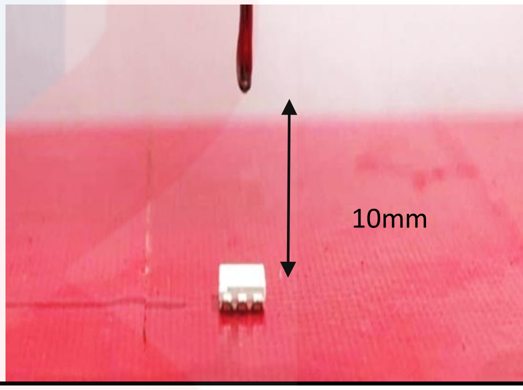
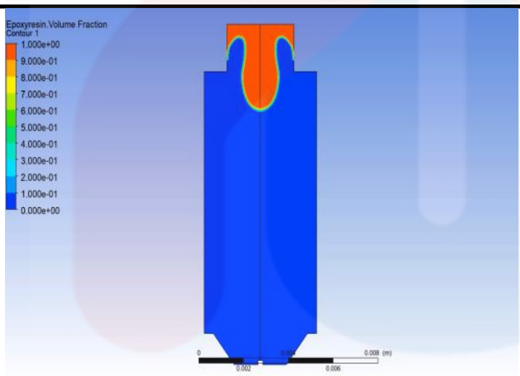
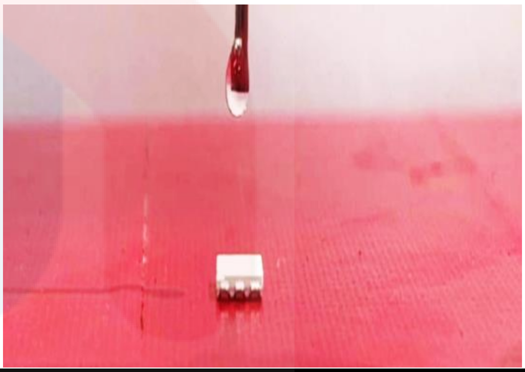
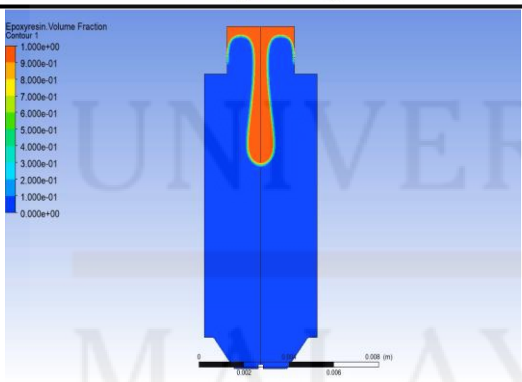
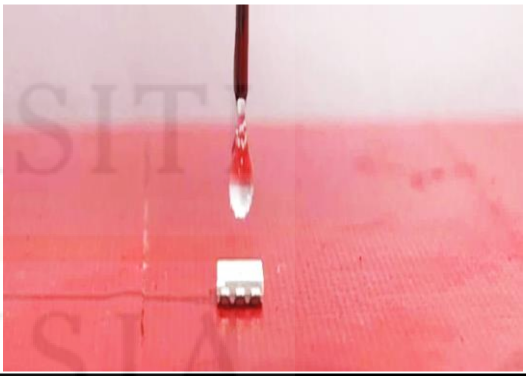
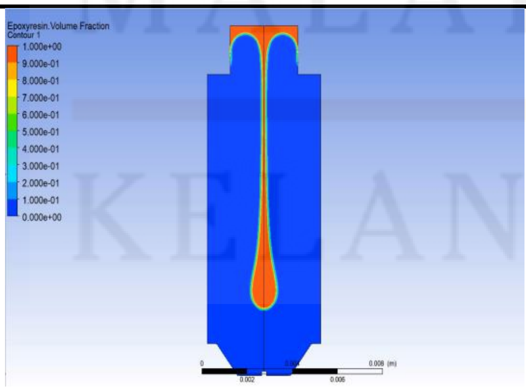
The comparison in Figure 4.1 and Table 1 primarily revolves around pressure values, serving as the variable for assessing different mesh types. Mesh-5 exhibits pressure values of 0 due to its inaccurate and low-quality geometry representation caused by excessively large element sizes, rendering it incompatible with the model and unsuitable for selection. Mesh-1, featuring 26418 nodes and 25796 elements, demonstrates a pressure value of 0.0000226 MPa. In contrast, Mesh-2, with 25432 nodes and 24816 elements, shows a slightly higher-pressure value of 0.0000228 MPa. The percentage difference between these readings is a mere 0.009%, falling below the 1% threshold.

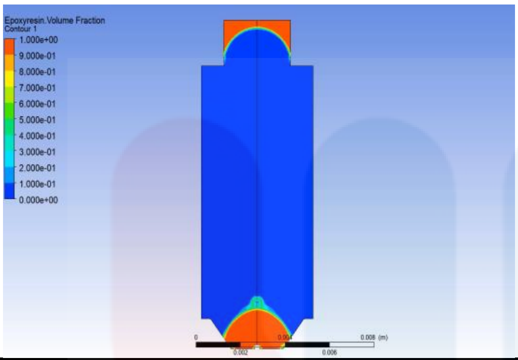
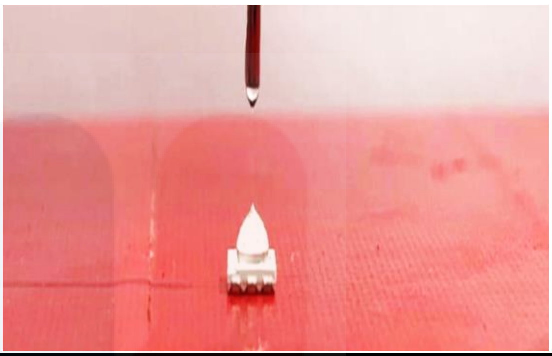
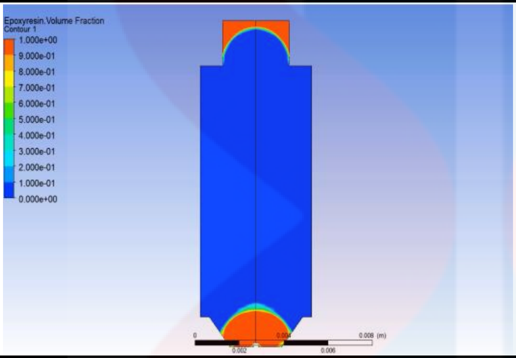
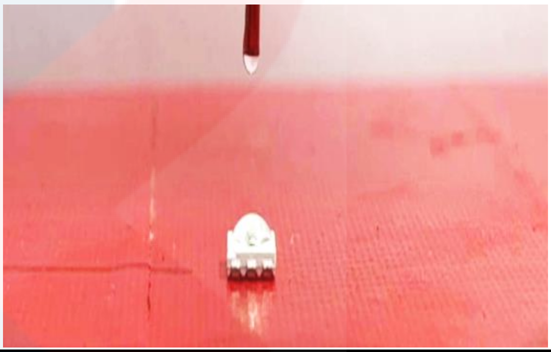
Moving to Mesh-3, equipped with 20400 nodes and 18920 elements, its pressure value is 0.0000120 MPa, revealing a substantial 162.8% difference compared to Mesh-2. Mesh-4, having 10,098 nodes and 9,722 elements, displays a pressure value of 0.0000011 MPa, indicating a 1272.7% difference relative to Mesh-3. During simulation, mesh selection hinges upon factors like complexity, convergence, accuracy requirements, and computational time needed for a 1e-6-time step calculation. Following a grid independence test, Mesh-2, featuring 0.049 mm element size, emerged as the preferred standard for this study's simulations.

Its near-identical results, with a minute percentage error of less than 1% compared to Mesh-3 (162.8%) and Mesh-4 (1272.7%), made it the optimal choice. It's essential to note that a higher cell count demands increased computational power. Mesh-2 required 9 hours for computation, whereas Mesh-1 demanded 12 hours. Consequently, Mesh-2, with its 0.049 mm element size, was selected for its ability to conserve energy and computing time.

4.3 Result of LED Encapsulation Process

Table 4.2: Comparison between Simulation and Experimental

Time(%)	Simulation (Fluent) Viscosity = 0.448 kg/m. *s*	Experimental
0		
10		
25		
50		

75		
100		

In this simulation, consistent parameters and boundary conditions were applied across the entire process, including inlet speed, contact angle, and injection time for the epoxy resins. Both simulation and experimental results were scrutinized, and Table 4.2 illustrates the comparison between the structures of the epoxy resins during the encapsulation process. The simulation aimed to analyze how the epoxy resins affected the ultimate structure of the encapsulant, covering the LED base, which measures approximately 3mm in diameter. The anticipated outcome of the simulation was a mirrored representation of the actual result in the final structure of the epoxy resins. The encapsulant structure for the EMC closely mirrors the experimental structure, with just a 5% difference. This demonstrates the near accuracy of the simulation setup for the EMC and suggests its potential applicability for comparing the final structure of other epoxy materials in encapsulation processes.

Examining Table 4.2 reveals that the structure of epoxy resins remains consistent from time durations 0% to 75%. However, discrepancies arise beyond the 75% mark, indicating potential inaccuracies. The simulation setup, particularly the meshing method, appears to contribute to inaccuracies around the 75% mark. A deeper investigation into the simulation setup is crucial to identify and rectify these errors for improved results. Similarly, at the 100%-time duration, discrepancies persist due to issues like the meshing method and wall angle settings. Therefore, modifying the simulation setup, such as extending the time for completing the EMC dispensing process, becomes necessary to address these inaccuracies.

4.4 Parametric Result

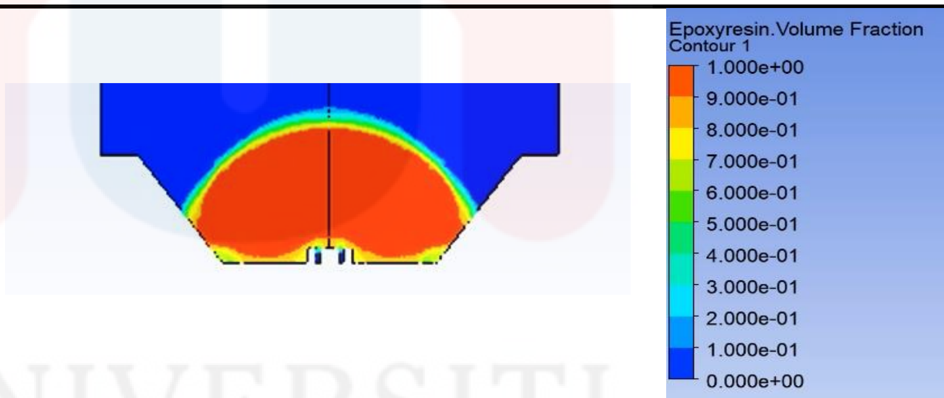
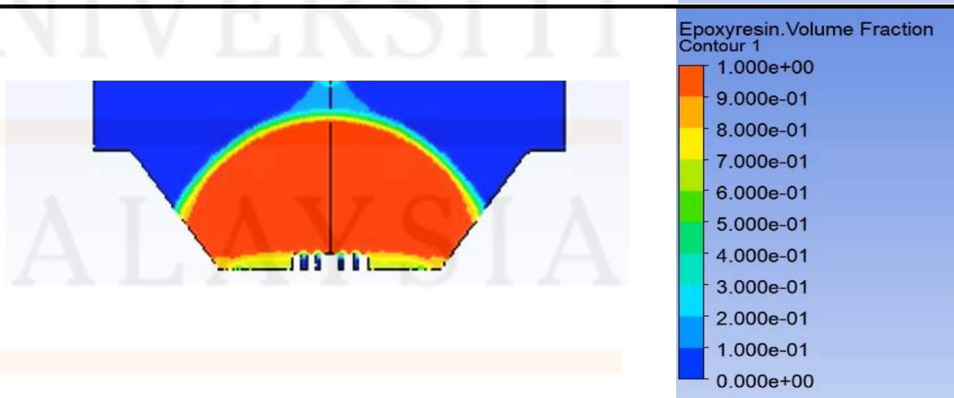
The exploration of parametric variations encompassing LED chip size, quantity, and angle yields profound insights into their distinct impacts on the LED encapsulation process. The investigation reveals that alterations in the size, number, and angle of LEDs serve as influential factors, leading to discernible changes in both pressure and velocity dynamics. These variations, in a cascading effect, contribute significantly to the formation of microvoids within the encapsulated structure. This section delves into the specific outcomes of the parametric study, shedding light on how the variations in LED characteristics intricately shape the dynamics of pressure, velocity, and microvoids formation. The findings not only deepen our comprehension of the intricacies within the LED encapsulation process but also pave the way for informed optimization strategies in this critical technological application.

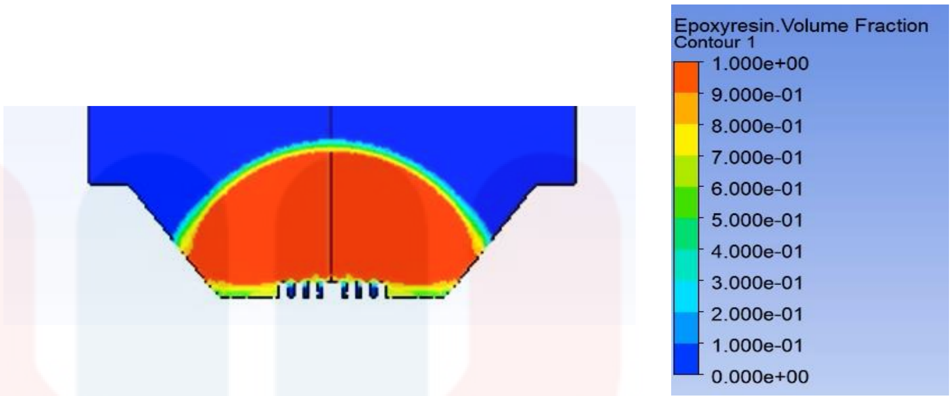
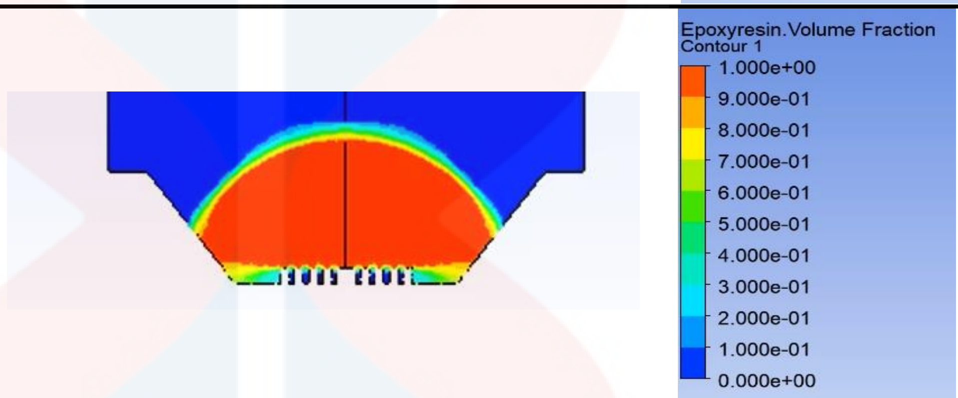
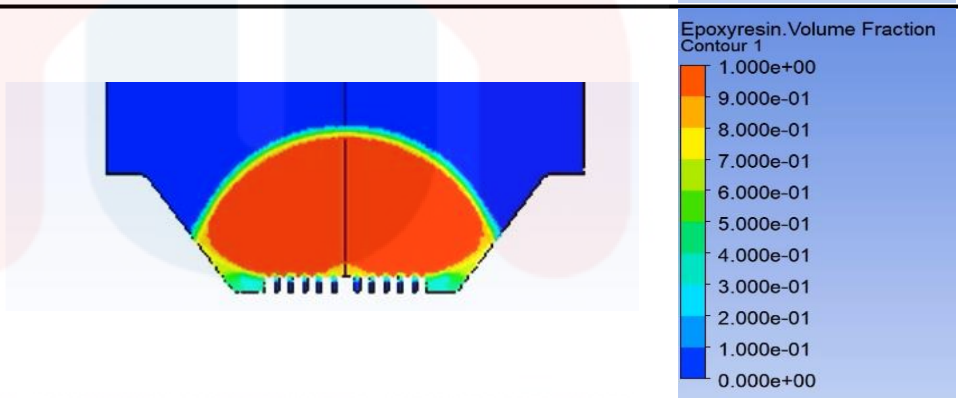
4.4.1 Impact of Chip Quantity

In this section, the influence of varying chip quantities on the encapsulation process is thoroughly examined. The study focuses on three key parameters: Microvoids Formation, Velocity Trends, and Pressure Dynamics. The outcomes of these investigations are presented in Table 4.3, showcasing the simulation results for different LED chip quantities.

4.4.1.1 Microvoids Formation for Chip Quantity

Table 4.3 : Microvoids Formation Analysis by Chip Quantity

Quantity of Chip Led	Microvoids formation
3	
5	

7	
9	
11	

The exploration of microvoids formation, contingent on the quantity of LED chips, unravels a discernible progression in the encapsulation process. With an increasing number of LED chips, a consequential rise in microhole occurrence becomes evident, substantiating a systematic relationship. Table 4.3 shows the microvoids formation analysis by chip quantity. Commencing with 3 LED chips, an observation reveals the emergence of two microvoids located strategically between the chips. Notably, the encapsulation material (EMC) provides comprehensive coverage, except for minor, isolated gaps in specific corners. As the chip count rises to 5, this phenomenon intensifies, resulting in four discernible microvoids. Critically, the

EMC's coverage diminishes, leaving distinct areas on the bottom surface of the LEDs inadequately covered. The trend persists with 7 LED chips, where the microvoids further proliferate, particularly at the base of the chips in the 6-LED configuration. This persistent insufficiency in EMC coverage leads to larger areas characterized by microvoids, echoing the observations in the 5-chip scenario. Upon integration of 9 LED chips, an additional eight microvoids surface, accompanied by an elevation in the height of the gaps in comparison to the 7-chip configuration. The EMC, once again, fails to achieve complete coverage, emphasizing discernible gaps. Next, with 11 LED chips, the microhole count escalates by ten, coupled with a notable widening of the gaps at the bottom of the LEDs, surpassing dimensions observed in the 5 and 7 LED chip configurations. This systematic exploration accentuates a clear correlation between the quantity of LED chips and the resultant microvoids dynamics, contributing valuable insights to the intricate interplay governing microvoids formation within the encapsulated structure.

4.4.1.2 Pressure Variations for Chip Quantity

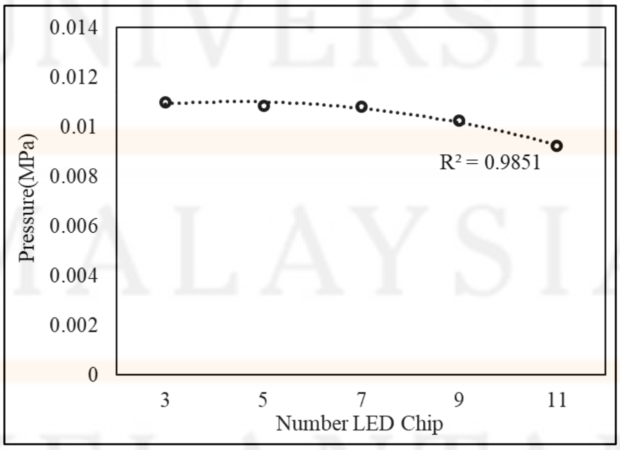


Figure 4.2 : Effect of LED Chip Quantity on Encapsulation Pressure

The exploration of pressure dynamics in tandem with microvoids formation, contingent upon the varying number of LED chips, necessitates a comprehensive analysis to elucidate the intricate relationship between these pivotal parameters. Figure 4.2 Show the effect of LED chip quantity on Encapsulation Pressure. Initiating with 3 LED chips, the recorded pressure stands at 0.01098 MPa, indicating a relatively elevated level. This observation suggests that a smaller quantity of LED chips may induce heightened resistance or constriction within the encapsulation process, contributing to an increase in overall pressure. Transitioning to 5 LED chips, a marginal decrease in pressure is noted, with the recorded value at 0.01086 MPa. This nuanced decline implies a dynamic equilibrium, where the system adjusts to the heightened complexity introduced by additional LED chips, potentially leading to a reduction in overall pressure. Continuing to 7 LED chips, the trend of decreasing pressure persists, with the recorded value at 0.0108 MPa. This ongoing reduction signifies the responsive behavior of the system to the escalating LED chip quantity, suggesting evolving microvoids formations or structural alterations within the encapsulation environment. Progressing to 9 LED chips, a more pronounced decrease in pressure is evident, with the recorded value at 0.01024 MPa. This substantial reduction points to a critical threshold where the system undergoes substantial changes, potentially associated with the emergence of larger microvoids or transformative shifts in the encapsulation structure. Culminating at 11 LED chips, the recorded pressure showcases a significant decrease to 0.00923 MPa. This observation suggests a pivotal shift in the encapsulation dynamics, potentially leading to a more intricate microvoids formation process as the LED chip quantity reaches its maximum. In synthesis, the observed pressure dynamics exhibit a discernible correlation with the quantity of LED chips, providing valuable insights into the intricate nature of microvoids formation within the encapsulated environment.

4.4.1.3 Velocity Trends for Chip Quantity

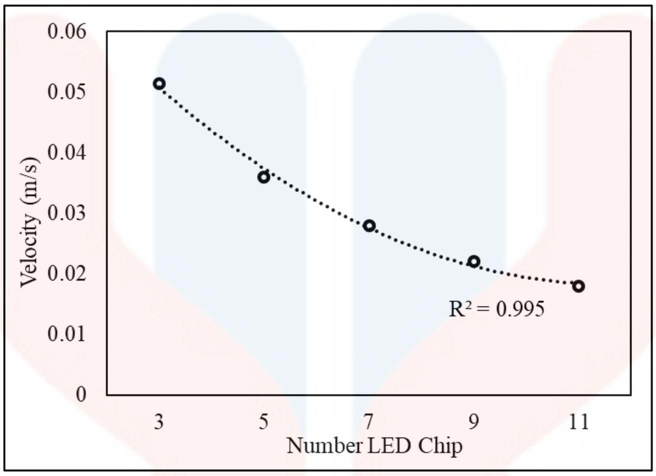


Figure 4.3 : Effect of LED Chip Quantity on Encapsulation Velocity

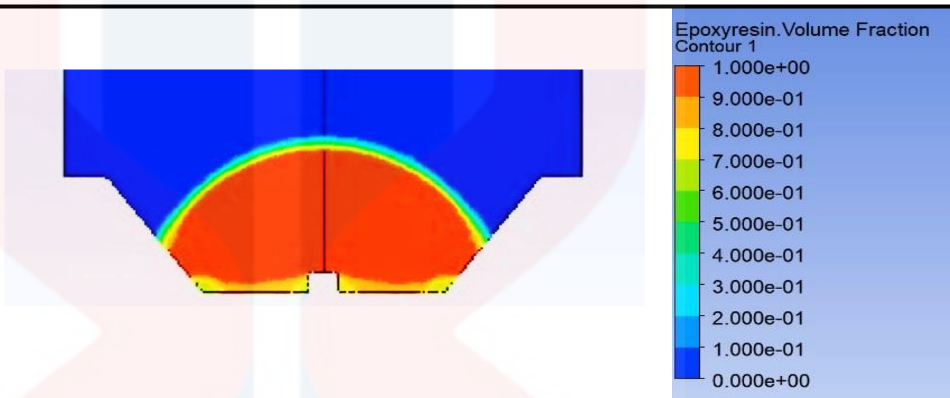
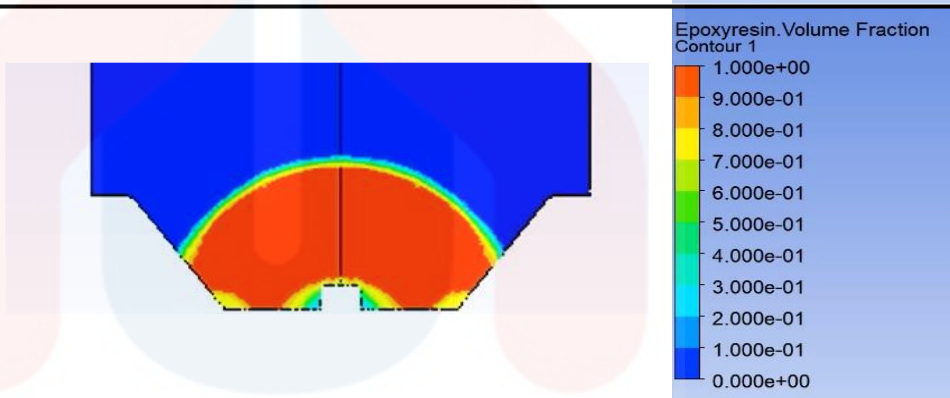
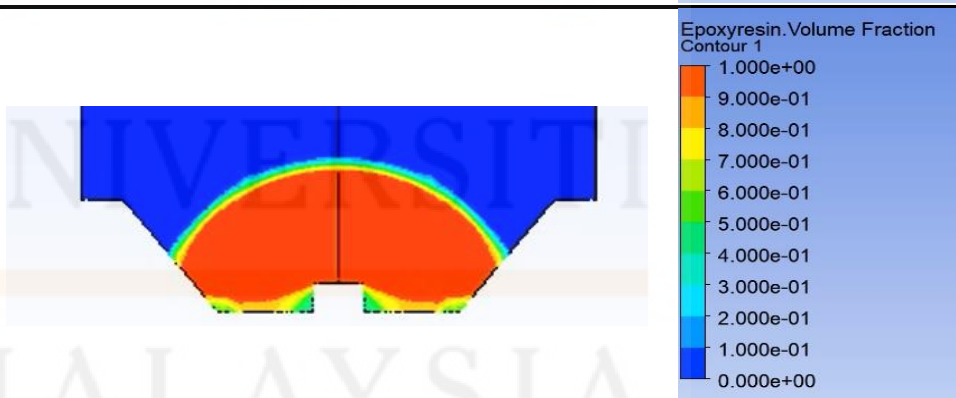
The examination of the intricate relationship between velocity dynamics and microvoids formation, influenced by varying LED chip quantities, unveils compelling trends that warrant meticulous exploration within the context of fluid dynamics. Commencing with 3 LED chips, the recorded velocity registers at 0.0514 m/s, indicative of a heightened fluid flow intensity. This initial observation suggests a state of efficient fluid dynamics, characterized by dynamic and vigorous flow patterns within the encapsulation process. Concurrently, micropores increase, forming a noteworthy trend aligning with the elevated fluid speed. Transitioning to 5 LED chips, a discernible reduction in velocity is noted, with the recorded value at 0.0360 m/s. This decrement implies a moderated fluid flow, signaling a gradual attenuation in flow intensity as a response to the incremental addition of LED chips. Correspondingly, the increase in micropores continues, indicating a dynamic relationship between fluid flow and microvoids formation. Upon reaching 7 LED chips, a notable surge in velocity is observed, reaching 0.0280 m/s. This upturn in velocity marks a potential tipping point in fluid dynamics, suggesting optimized flow conditions or altered microvoids formation patterns influenced by the increased quantity of LED chips. The concurrent increase in micropores further substantiates the intricate correlation between fluid speed and microvoids formation. Advancing to 9 LED chips, a discernible decrease in velocity is evident, recorded at 0.0221 m/s. This reduction signifies a complex interaction between the heightened LED chip quantity and resultant velocity dynamics, possibly influencing microvoids formation with a decrease in fluid speed. The consistent increase in micropores persists, emphasizing the symbiotic relationship between fluid dynamics and microvoids formation. The final data point at 11 LED chips indicates a further reduction in velocity to 0.0180 m/s. This diminishing trend underscores a critical threshold, signaling substantial changes in the system that may impact microvoids formation dynamics. As fluid speed decreases, the increase in micropores persists, accentuating the intricate interplay between fluid dynamics and microvoids formation. In synthesis, the observed velocity dynamics portray a nuanced relationship with the quantity of LED chips. The initial increase in velocity is succeeded by subsequent fluctuations, reflecting a complex interplay between LED chip quantity and microvoids formation.

4.4.2 Analysis of Chip Size

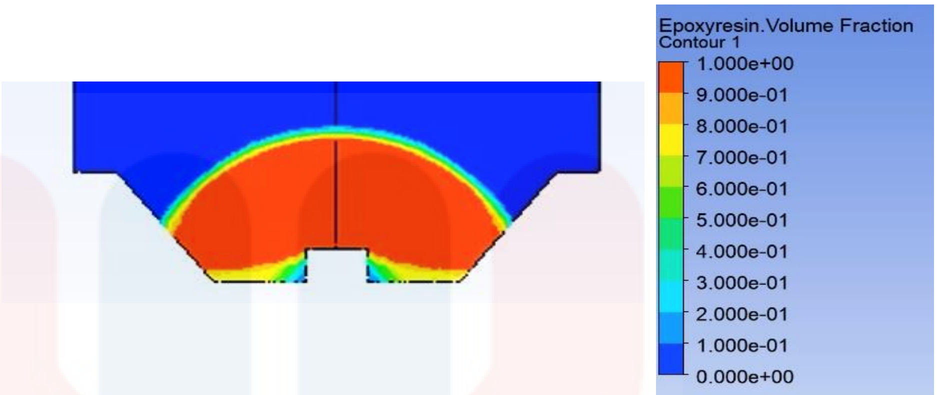
In this section, the influence of varying chip Size on the encapsulation process is thoroughly examined. The study focuses on three key parameters: Microvoids Formation, Velocity Trends, and Pressure Dynamics. The outcomes of these investigations are presented in Table 4.4, showcasing the simulation results for different LED chip Size.

4.4.2.1 Microvoids Formation for Chip Size

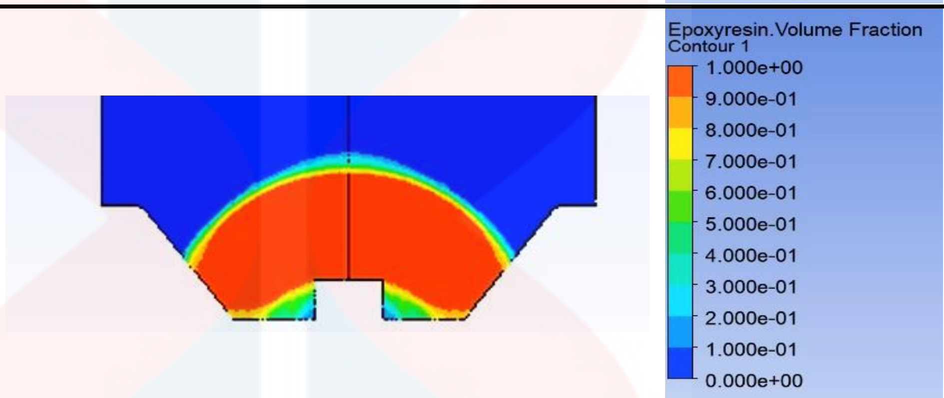
Table 4.4 : Microvoids Formation Analysis by Chip Size

Chip Size of Led	**Microvoids formation**
0.20 X 0.15	
0.25 X 0.20	
0.30 X 0.25	

0.35 X 0.30



0.40 X 0.35



The investigation into the impact of LED chip size on the encapsulation process unveils noteworthy observations, shedding light on the intricate relationship between chip dimensions and microvoids formation. Observations at a chip size of 0.20x0.15 reveal an absence of apparent micropores. However, discernible gaps exist at the bottom where the encapsulation material (EMC) does not fully cover the LED. This suggests a critical threshold in chip size where micropore formation becomes discernible, accompanied by incomplete coverage at the LED's base. Upon increasing the LED chip size to 0.25x0.20, micropores become evident around the LED chip, while corners exhibit no discernible gaps. The EMC effectively covers the bottom of the LED at this size, marking a nuanced change in microvoids formation as a response to alterations in chip dimensions. Advancing further to a chip size of 0.30x0.25, both micropores and gaps at the bottom of the LED increase, becoming more noticeable. This suggests an escalating impact on microvoids formation with larger chip sizes, contributing to a more complex encapsulation structure. At a size of 0.35x0.30, both micropores and bottom gaps further enlarge, highlighting the continued influence of chip size on the intricacies of microvoids formation. This observation accentuates the critical role of LED chip dimensions in shaping the dynamics of microvoids within the encapsulated structure. When the LED chip size reaches 0.40x0.35, there are fewer gaps at the bottom, but micropores become more prominent around the LED chip. This implies a trade-off between bottom coverage and micropore formation, showcasing the delicate balance influenced by varying chip sizes. So, the analysis of chip size indicates a nuanced interplay between dimensions and microvoids formation.

4.4.2.2 Pressure Variations for Chip Size

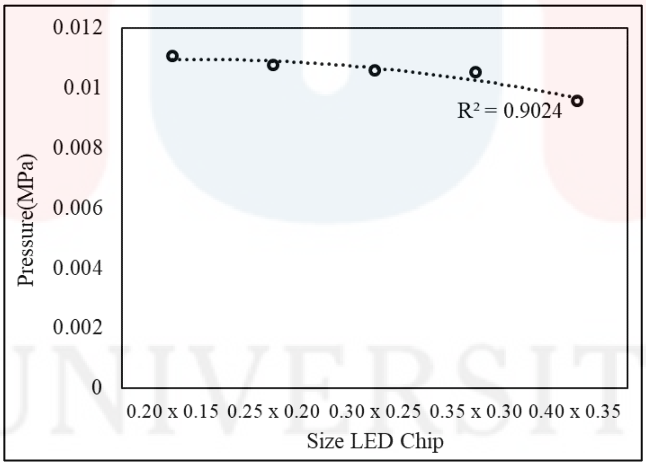


Figure 4.5 : Effect of LED Chip Size on Encapsulation Pressure

Figure 4.5 shows the effect of LED Chip Size on Encapsulation Pressure. At the smallest LED chip size of 0.20x0.15, the encapsulation process exhibits higher pressure levels at 0.01105 MPa. This indicates increased resistance or constriction, resulting in elevated pressure. Notably, at this size, micropores are conspicuously absent, establishing a clear inverse correlation between elevated pressure and the absence of micropores. Upon increasing the LED chip size to 0.25x0.20, a subtle decrease in pressure to 0.01075 MPa is observed. This nuanced reduction suggests a delicate balance between structural constraints and the complexity introduced by a larger chip size. Intriguingly, the emergence of micropores becomes evident, illustrating a dynamic relationship where decreasing pressure corresponds to an increase in micropore formation. Advancing to a larger LED chip size of 0.30x0.25 results in a further decrease in pressure to 0.01057 MPa. This observation reinforces the proportional relationship between larger chip sizes, decreased pressure, and more noticeable micropores within the encapsulated structure. The data underscores that as the LED chip size increases, both pressure and micropore formation undergo corresponding changes.

At 0.35x0.30, the pressure continues to decrease slightly to 0.01052 MPa. Concurrently, micropores become more prominent, solidifying the consistent trend observed throughout the analysis. Larger LED chip sizes consistently correlate with reduced pressure and increased micropore formation, indicating a systematic relationship in the encapsulation dynamics. The final data point at 0.40x0.35 demonstrates a further reduction in pressure to 0.00955 MPa. Micropores continue to increase in prominence, emphasizing the reciprocal relationship between larger LED chip sizes, decreased pressure, and more pronounced micropores within the encapsulated structure. So, the observed data highlights a nuanced interplay between LED chip sizes, pressure dynamics, and the presence or absence of micropores. The inverse correlation between pressure and micropores becomes apparent with larger chip sizes, offering valuable insights for optimizing LED chip dimensions and refining the encapsulation process.

4.4.2.3 Velocity Trends for Chip Size

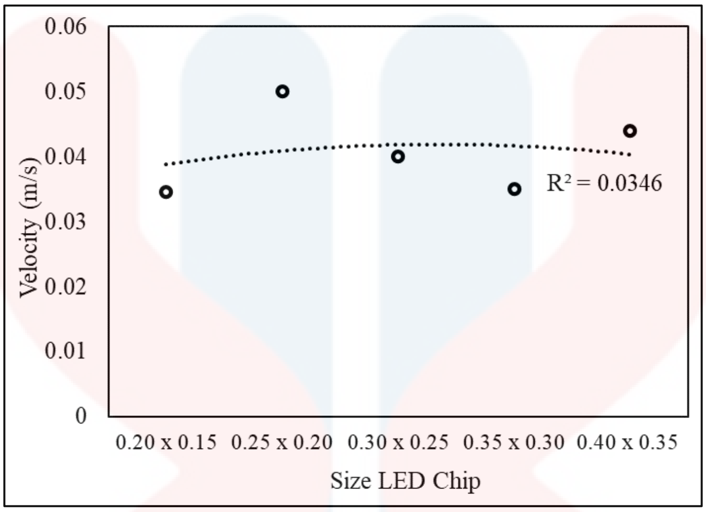


Figure 4.6 : Effect of LED Chip Size on Encapsulation Velocity

The examination of velocity dynamics, micropore formation, and bottom gaps concerning different sizes of LED chips reveals intricate relationships among these crucial parameters. Figure 4.6 show the effect of LED Chip Size on encapsulation velocity at the smallest LED chip size of 0.20x0.15, a moderate flow velocity of 0.0346 m/s is observed, indicating a balanced fluid flow intensity. Micropores are present, suggesting that fluid dynamics at this velocity allow for the formation of observable micropores. Upon increasing the LED chip size to 0.25x0.20, the flow velocity significantly rises to 0.0500 m/s. This heightened fluid flow may contribute to more pronounced micropores. Notably, as the speed increases, the gaps at the bottom of the LED diminish, potentially influencing micropore formation. Transitioning to a larger chip size of 0.30x0.25, a moderate flow velocity of 0.0400 m/s is observed. Despite the moderate speed, micropores persist, indicating that factors beyond velocity influence micropore formation. The dynamics are complex, and the formation of micropores may involve other contributing factors. At 0.35x0.30, a larger chip size maintains a flow velocity of 0.0350 m/s. Despite the relatively low speed, micropores are still observable.

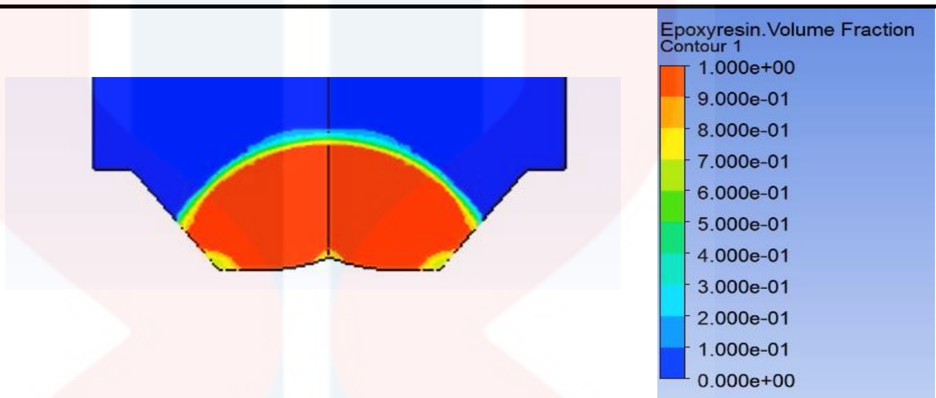
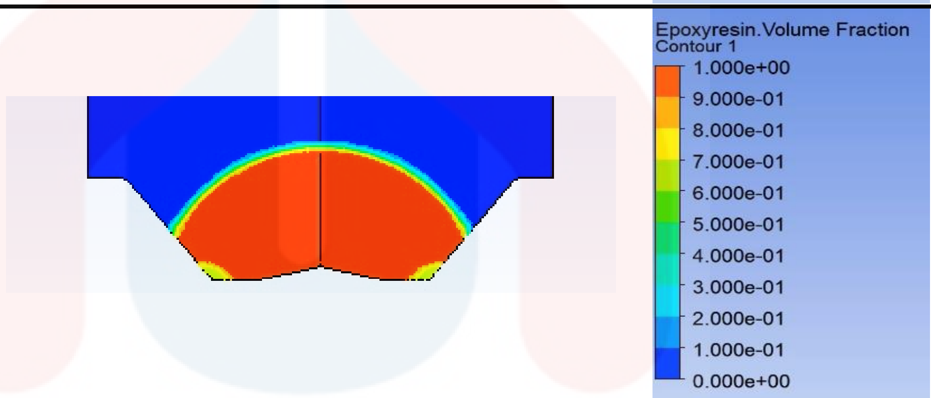
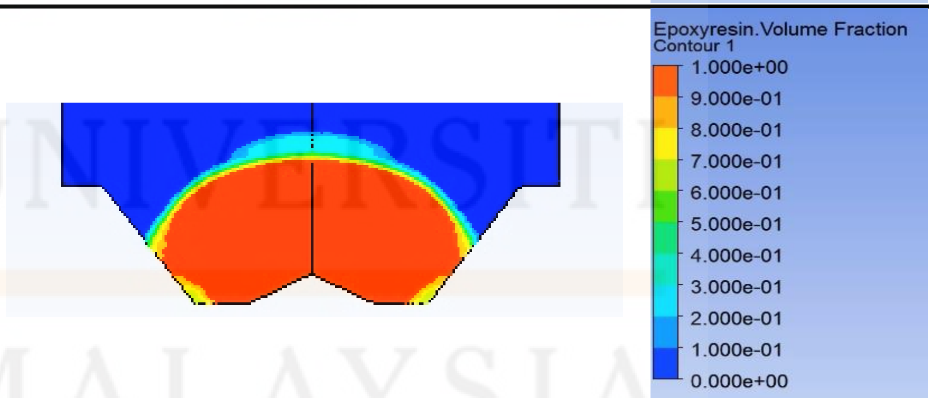
This emphasizes that micropore formation is not solely dependent on fluid speed but may be influenced by other aspects related to chip size. In the case of the largest chip size, 0.40x0.35, the flow velocity increases to 0.0440 m/s. As the velocity rises, it is observed that the gaps at the bottom of the LED become smaller, leading to a significant increase in micropores. This suggests a correlation between increased velocity, reduced bottom gaps, and enhanced micropore formation. Additional observations highlight that an increase in flow velocity tends to facilitate micropore formation, as observed in both the smallest and largest LED chip sizes. This phenomenon is attributed to smaller gaps at the bottom of the LED resulting from increased velocity, contributing to a significant increase in micropores. Conversely, when the flow velocity decreases, micropores are reduced, potentially accompanied by the formation of more extensive gaps at the bottom of the LED.

4.4.3 Influence of Chip Angle

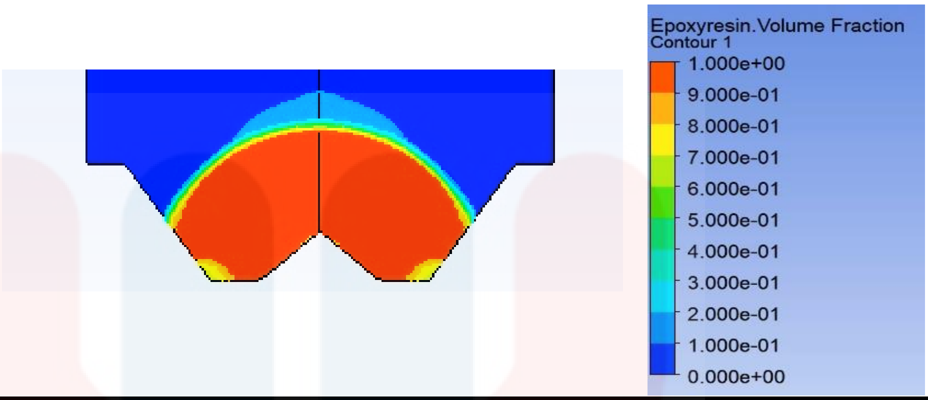
In this section, the influence of varying chip angles on the encapsulation process is thoroughly examined. The study focuses on three key parameters: Microvoids Formation, Velocity Trends, and Pressure Dynamics. The outcomes of these investigations are presented in Table 4.5, showcasing the simulation results for different LED chip angles.

4.4.3.1 Microvoids Formation for Chip Angle

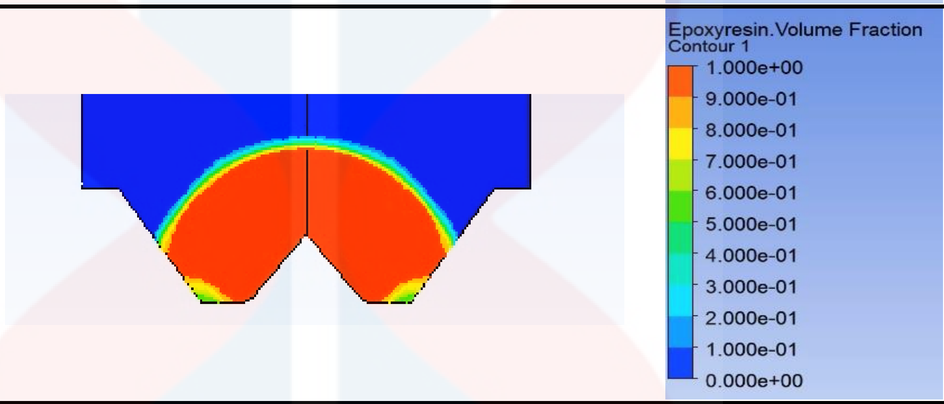
Table 4.5 : Microvoids Formation Analysis by Chip Angle

Angle of Chip Led	Microvoids formation
0.5	
0.65	
0.7	

0.8



0.95



The investigation into the influence of LED chip angle on microvoids formation reveals distinctive patterns and characteristics, providing valuable insights into the complex interplay between chip orientation and the resultant microvoids dynamics during the LED encapsulation process. At an LED chip angle of 0.5, three conspicuous microvoids become apparent, positioned strategically in the corners of the LED. These microvoids contribute to the overall microvoids structure, marking an initial observation of microvoids formation influenced by chip orientation. Upon increasing the LED chip angle to 0.65, a noteworthy observation is made. The microhole shapes closely resemble those observed at an angle of 0.5, but with a reduction in the number of microvoids by one. Despite this reduction, the injection-induced shape of the EMC drop remains consistent, implying a degree of stability in microvoids characteristics. The LED chip angle of 0.7 stands out as particularly intriguing. Here, the observations reveal the presence of obvious bubbles on the surface of the EMC drop formed during the injection process. The EMC drop exhibits a relatively flat shape with discernible micropores, presenting a distinctive departure in microvoids characteristics compared to previous angles. As the LED chip angle increases to 0.8, a noticeable transformation occurs in the shape of the EMC droplet. It becomes more prominent, and the micropores within the structure become more pronounced. This suggests an evolving trend in microvoids formation dynamics associated with changes in chip angle. Further increasing the angle to 0.95 results in a more prominent shape in the EMC droplet, accompanied by increased visibility of micropores compared to the angle of 0.8. This heightened prominence at 0.95 implies a correlation between chip angle and the observable features of microvoids, further emphasizing the intricate relationship between the two. So, these observations underscore the nuanced influence of LED chip angle on the formation of microvoids during the encapsulation process. The variations in chip angles introduce distinct characteristics in microhole shapes, EMC drop formations, and the prominence of micropores. This understanding contributes to a comprehensive comprehension of how chip orientation intricately impacts the microvoids landscape.

4.4.3.2 Pressure Variations for Chip Angle

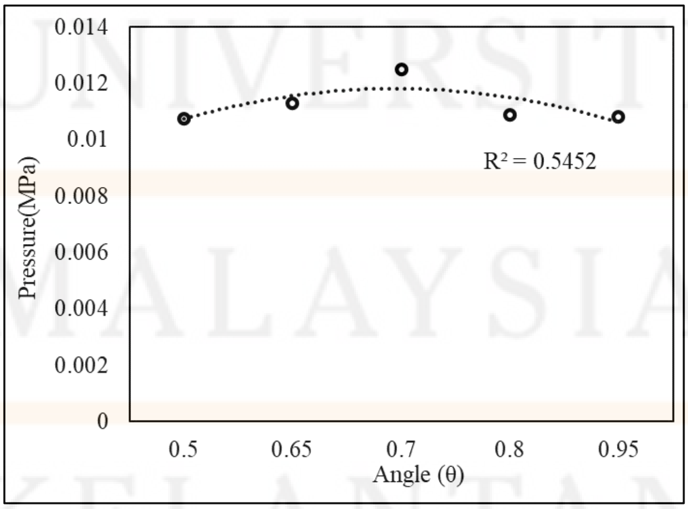


Figure 4.7 : Effect of LED Chip Angle on Encapsulation Pressure

At an LED chip angle of 0.5, where three conspicuous microvoids are evident, the corresponding pressure is measured at 0.01076 MPa. This initial observation establishes a baseline for the pressure dynamics associated with microvoids formation influenced by chip orientation. Upon increasing the LED chip angle to 0.65, a noteworthy pattern emerges. Despite the microhole shapes closely resembling those at an angle of 0.5, with a reduction in the number of microvoids by one, the pressure increases to 0.01129 MPa. This implies that, although the microvoids characteristics remain stable, the pressure experiences a slight elevation with the change in chip angle. The LED chip angle of 0.7 introduces a distinct scenario. Here, with the presence of obvious bubbles and discernible micropores, the pressure notably increases to 0.01249 MPa. The juxtaposition of microvoids features and increased pressure suggests a potential correlation between the complexity of microvoids and elevated pressure levels at this angle.

As the LED chip angle further increases to 0.8, a noticeable transformation in the shape of the EMC droplet occurs. This is accompanied by more pronounced micropores and a pressure reading of 0.01088 MPa. The data suggests a potential inverse correlation between pressure and microvoids complexity, where an increase in microvoids intricacy corresponds to a decrease in pressure. Continuing the trend, a higher LED chip angle of 0.95 results in a more prominent shape in the EMC droplet, increased visibility of micropores, and a pressure reading of 0.01082 MPa. The consistency in pressure readings between angles of 0.8 and 0.95, despite varying microvoids intricacies, hints at a potential saturation point where pressure reaches equilibrium even as microvoids characteristics evolve. So, the nuanced influence of LED chip angle on pressure variations is evident. While certain trends suggest a correlation between microvoids complexity and pressure, the intricacies of this relationship warrant further investigation.

4.4.3.3 Velocity Trends for Chip Angle

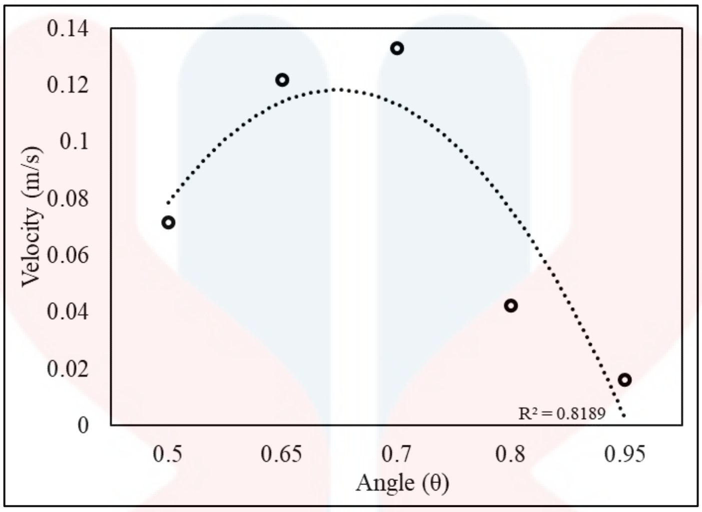


Figure 4.8 : Effect of LED Chip Angle on Encapsulation Velocity

At an LED chip angle of 0.5, where three conspicuous microvoids are evident, the corresponding velocity is measured at 0.0715 m/s. This initial observation establishes a baseline for the velocity dynamics associated with microvoids formation influenced by chip orientation. Upon increasing the LED chip angle to 0.65, a noteworthy acceleration in velocity is observed, reaching 0.1218 m/s. This increase in speed aligns with the reduction in the number of microvoids, suggesting a potential correlation between higher velocity and reduced microvoids complexity. The LED chip angle of 0.7 introduces a further increase in velocity to 0.1329 m/s. This heightened velocity coincides with the presence of obvious bubbles and discernible micropores. The elevated speed may contribute to the observed complexity in microvoids formation at this angle. As the LED chip angle further increases to 0.8, there is a significant decrease in velocity to 0.0423 m/s. This reduction in speed correlates with a noticeable transformation in the shape of the EMC droplet and more pronounced micropores. The inverse relationship between velocity and microvoids intricacy suggests a potential influence of fluid dynamics on microvoids formation.

Continuing the trend, a higher LED chip angle of 0.95 results in a substantial decrease in velocity to 0.0162 m/s. The lowest velocity in the dataset aligns with a more prominent shape in the EMC droplet, increased visibility of micropores, and a potential saturation point where further reduction in speed may not significantly alter microvoids characteristics.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

In conclusion, this study delves into the critical relationship between LED design parameters and microvoids formation during the encapsulation process. LEDs, integral to modern technology, rely on encapsulation, particularly with Epoxy Molding Compound (EMC), to ensure longevity. However, microvoids, small air bubbles formed during encapsulation, pose challenges to LED reliability. The research investigated the effects of LED design on microvoids using experiments and ANSYS simulations. Key parameters, such as LED structure, chip size, and dispensing conditions, were analyzed. The study revealed that optimizing LED design could minimize microvoids, enhancing mechanical stability. The significance lies in empowering LED manufacturers to refine encapsulation processes, ultimately improving LED performance. The findings also highlight the potential to extend LED lifespan by minimizing microvoids. In summary, this study advances our understanding of LED design's impact on microvoids formation, providing a basis for optimizing LED manufacturing and contributing to more efficient and reliable LED devices.

5.2 Recommendations

Considering the findings uncovered in this study, several key recommendations are proposed to guide future endeavours in LED encapsulation. Firstly, further exploration into optimizing dispensing parameters such as dispensing speed, curing time, and environmental conditions is warranted to minimize the formation of microvoids during the encapsulation process, ultimately enhancing LED reliability. Secondly, a comprehensive investigation into alternative encapsulation materials beyond Epoxy Molding Compound (EMC) is advised. Materials exhibiting improved thermal conductivity, reduced susceptibility to microvoids formation, and enhanced protective properties should be thoroughly examined. Thirdly, investing in advanced simulation techniques, including extending simulation durations, incorporating additional variables, and validating results through experimental data, can refine the accuracy of LED encapsulation simulations. Additionally, the implementation of real-time monitoring systems during the dispensing process to track microvoids formation is recommended for immediate adjustments and optimization. Collaboration between researchers and industry stakeholders is encouraged to facilitate knowledge exchange and practical implementation of cutting-edge research findings. Standardizing LED encapsulation processes, conducting lifecycle assessments of LED devices, and continuous monitoring of LED performance in real-world applications are crucial for ensuring sustainable and high-quality LED products.

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