HEAT TRANSFER ANALYSIS OF IN-WHEEL ELECTRIC MOTOR HOUSING WITH DIFFERENT COOLING FIN ARRANGEMENT USING ANSYS

DASI RAVI TEJA[1], B.JITHENDER[2]

[1]M. Tech Student, Department of Mechanical Engineering, Vaagdevi College of Engineering, Khammam - Warangal Hwy, Road, Bollikunta, Telangana 506005

[2]Assistant Professor, Department of Mechanical Engineering, Vaagdevi College of Engineering, Khammam - Warangal Hwy, Road, Bollikunta, Telangana 506005

Abstract The rapid growth of electric vehicles (EVs) has increased the demand for efficient thermal management systems to ensure the reliable operation of in-wheel electric motors. During continuous operation, the motor generates a significant amount of heat due to copper losses, iron losses, eddy current losses, and mechanical friction. Excessive temperature adversely affects motor efficiency, permanent magnet performance, insulation life, and overall system reliability. Therefore, an effective cooling system is essential to maintain the motor within its permissible operating temperature. This research presents a numerical investigation of heat transfer characteristics of an in-wheel electric motor housing with different cooling fin arrangements using ANSYS Workbench.

Four innovative cooling fin configurations, namely Straight Fin (baseline), Wave Fin, Zig-Zag Fin, and Rounded Layer Fin, are designed using SolidWorks while maintaining identical housing dimensions, fin height, fin thickness, and fin spacing to ensure a fair comparison. Aluminium Alloy 6061, Aluminium Alloy 7075, and Magnesium Alloy AZ91D are selected as candidate materials due to their excellent thermal conductivity, lightweight characteristics, and suitability for electric vehicle applications. Steady-state thermal analysis, and Static Structural analysis are performed under identical operating conditions by applying a uniform heat source and forced air cooling. The performance of each fin arrangement is evaluated based on maximum temperature, minimum temperature, temperature distribution, heat flux, deformation, equivalent stress, and factor of safety. Unlike previous studies that focused only on conventional straight, slanting, and transverse fin arrangements, this research extends the existing work by introducing advanced fin geometries capable of enhancing convective heat transfer while minimizing weight and maintaining structural integrity. The comparative investigation identifies the optimum cooling fin arrangement that provides maximum heat dissipation, lower operating temperature, reduced thermal resistance, and improved thermal efficiency. The findings of this work provide practical design guidelines for developing high-performance air-cooled in-wheel electric motor housings for next-generation electric vehicles.

1. Introduction

The increasing demand for sustainable transportation has accelerated the development of electric vehicles (EVs) worldwide. Electric vehicles offer several advantages over conventional internal combustion engine vehicles, including zero tailpipe emissions, higher energy efficiency, reduced maintenance requirements, and lower operating costs. As governments and automobile manufacturers continue to promote environmentally friendly transportation, the design and performance of electric propulsion systems have become an important area of research and development.

Among the various propulsion technologies used in electric vehicles, the in-wheel electric motor has emerged as an innovative solution due to its compact design and direct-drive mechanism. Unlike conventional electric drive trains, where the motor is connected to the wheels through a gearbox, differential, and drive shafts, an in-wheel motor is directly integrated into the wheel hub. This eliminates several mechanical transmission components, reducing mechanical losses and improving overall vehicle efficiency. The compact arrangement also provides greater design flexibility, better utilization of vehicle space, improved torque control, and enhanced driving performance. In-wheel motors are increasingly used in electric passenger vehicles, electric bicycles, electric scooters, autonomous vehicles, robotic vehicles, military vehicles, and lightweight commercial transportation systems.

An in-wheel electric motor consists of several major components including the stator, rotor, permanent magnets, shaft, bearings, motor housing, and cooling system. The motor housing is one of the most important structural components because it supports the internal motor assembly while protecting it from dust, moisture, vibration, and mechanical damage. In addition to providing structural support, the motor housing acts as the primary path for transferring heat generated inside the motor to the surrounding environment. Therefore, the thermal performance of the motor housing plays a significant role in maintaining the efficiency and reliability of the electric motor.

1.1 In-Wheel Electric Motor

An in-wheel electric motor, also referred to as a hub motor or wheel hub motor, is an electric propulsion system in which the motor is directly integrated inside the wheel hub. Unlike conventional electric drivetrains, the in-wheel motor eliminates the need for mechanical transmission components such as the gearbox, clutch, differential, universal joints, and drive shafts. Instead, the electric motor delivers torque directly to the wheel, resulting in a more efficient transmission of power.

The concept of in-wheel motors was first proposed more than a century ago; however, advances in permanent magnet materials, power electronics, battery technology, and lightweight materials have made their practical implementation feasible in modern electric vehicles. Today, in-wheel motors are increasingly used in passenger electric vehicles, electric bicycles, electric scooters, autonomous vehicles, military vehicles, agricultural machinery, and robotic platforms.

The elimination of conventional transmission components not only reduces mechanical power losses but also simplifies the overall drivetrain, leading to improved packaging efficiency and increased interior space. Furthermore, independent wheel control enables advanced vehicle stability systems, torque vectoring, regenerative braking, and improved driving dynamics.

1.2 Need of the study

As electric vehicles continue to become more compact and powerful, effective thermal management of in-wheel electric motors is increasingly important. Improving the design of external cooling fins offers a practical and economical way to enhance heat dissipation without adding pumps, coolant circuits, or complex auxiliary systems. Advanced fin arrangements can increase the effective surface area, improve airflow characteristics, and reduce motor operating temperature while preserving the simplicity and reliability of air-cooled systems.

For this reason, the present research focuses on evaluating different cooling fin arrangements for an in-wheel electric motor housing to contribute toward more efficient, reliable, and lightweight electric vehicle propulsion systems.

1.3 Aim of the study

The primary aim of this project is to investigate and optimize the thermal performance of an in-wheel electric motor housing by comparing different cooling fin arrangements using ANSYS. The study aims to identify the most efficient fin geometry capable of improving heat dissipation, reducing motor operating temperature, and enhancing the overall reliability and efficiency of electric vehicle propulsion systems. Cooling fin configurations, namely Straight Fin (baseline), Wave Fin, Zig-Zag Fin, and Rounded Layer Fin, are designed using SolidWorks while maintaining identical housing dimensions, fin height, fin thickness, and fin spacing to ensure a fair comparison. Aluminium Alloy 6061, Aluminium Alloy 7075, and Magnesium Alloy AZ91D are selected as candidate materials due to their excellent thermal conductivity, lightweight characteristics, and suitability for electric vehicle applications. Steady-state thermal analysis, and Static Structural analysis are performed under identical operating conditions by applying a uniform heat source and forced air cooling. The scope of this research is limited to the numerical analysis of air-cooled in-wheel electric motor housings under steady-state operating conditions. The study includes the design of different external cooling fin arrangements, thermal analysis, and structural evaluation using ANSYS software.

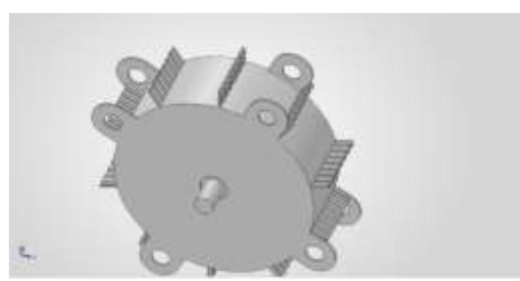
2. LITERATURE REVIEWS

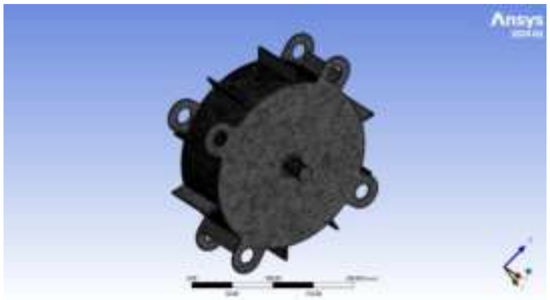
Li et al. (2025) presented a comprehensive review of thermal management techniques for electric motors used in electric vehicle applications. The authors compared various cooling methods including air cooling, liquid jacket cooling, spray cooling, immersion cooling, heat pipe cooling, potting cooling, and direct winding cooling.

Raj et al. (2024) reviewed the relationship between electric motor cooling techniques and motor power ratings in electric vehicles. The study discussed how increasing motor power density results in greater heat generation, making thermal management an essential requirement for maintaining efficiency and reliability.

Madhavan et al. (2023) investigated thermal management techniques for induction motors by combining numerical simulation with a detailed review of cooling strategies. The study highlighted that excessive operating temperatures reduce motor efficiency and accelerate insulation degradation, leading to shorter service life and higher maintenance costs.

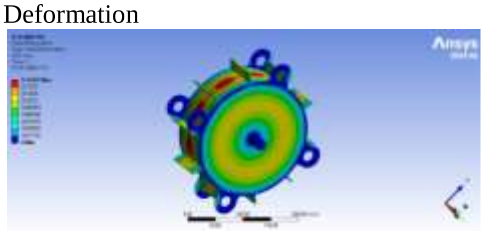
3. MODELING IN ANSYS





4. RESULTS AND ANALYSIS

Straight fins
Az91d
Deformation

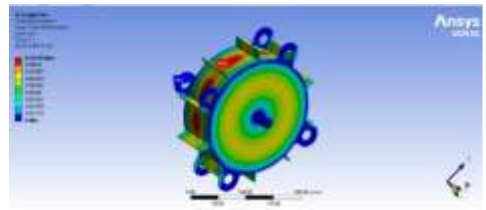


Stress

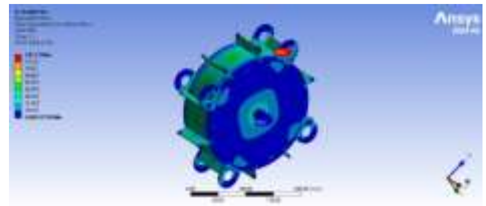
Strain

Al-6061

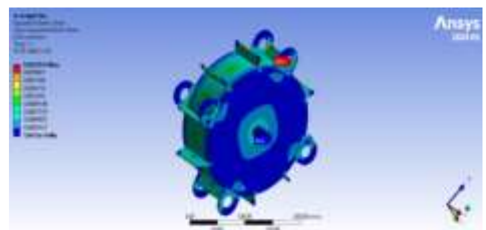
Deformation



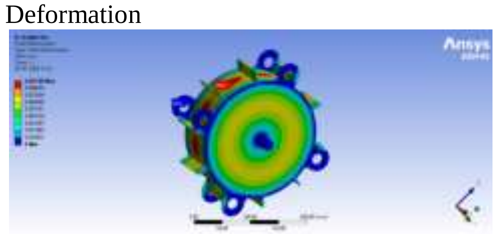
Stress



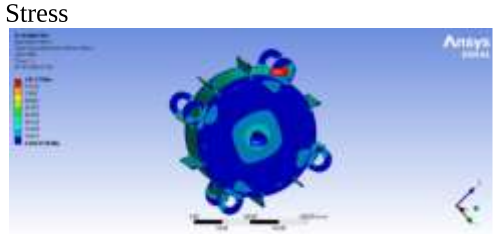
Strain



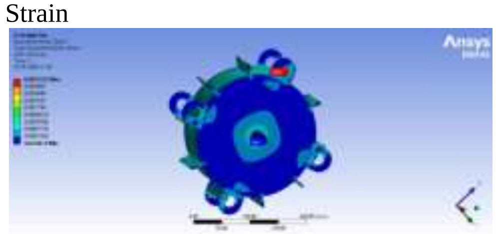
Al-7075
Deformation



Stress



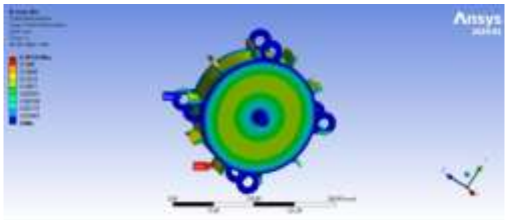
Strain



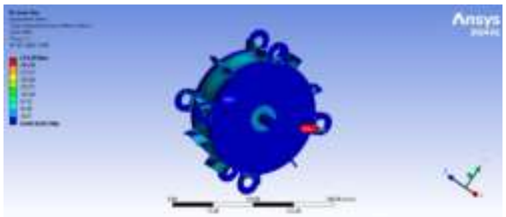
Wave fins

Az91d

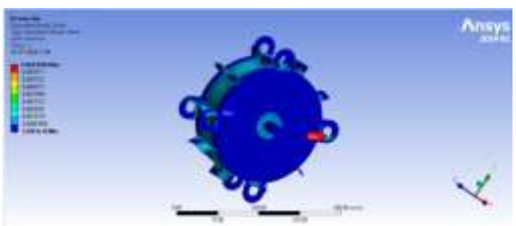
Deformation



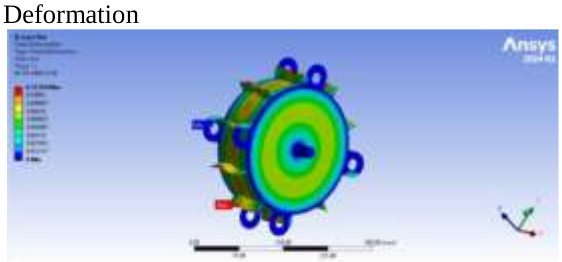
Stress



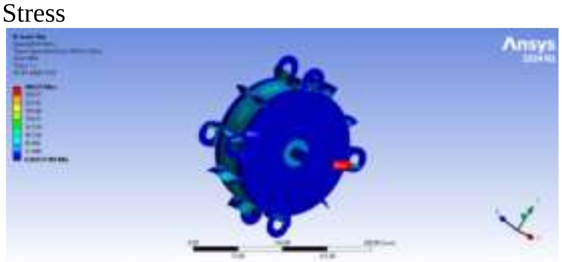
Strain



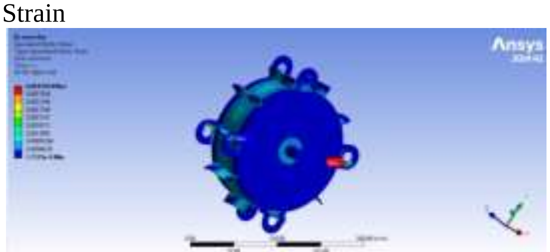
Al-6061
Deformation



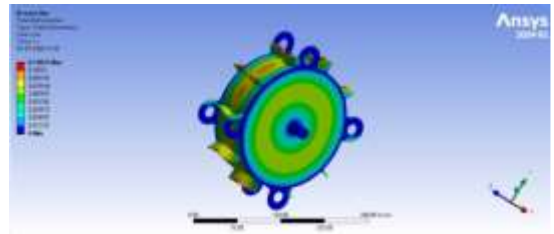
Stress



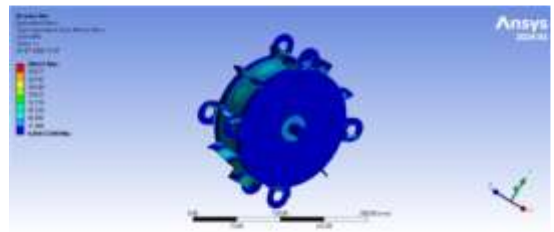
Strain



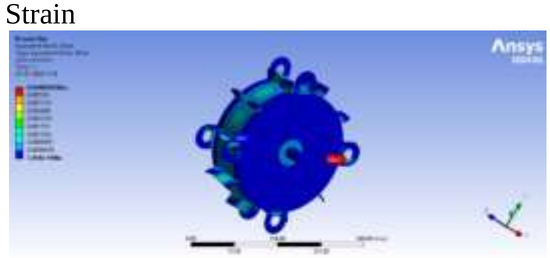
Al-7075
Deformation



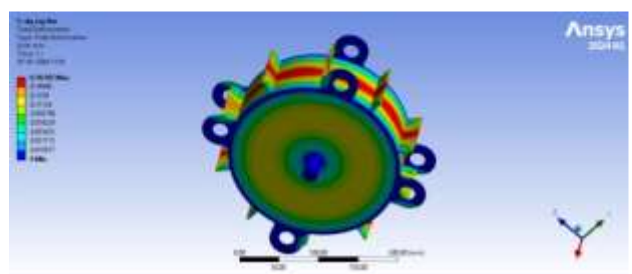
Stress



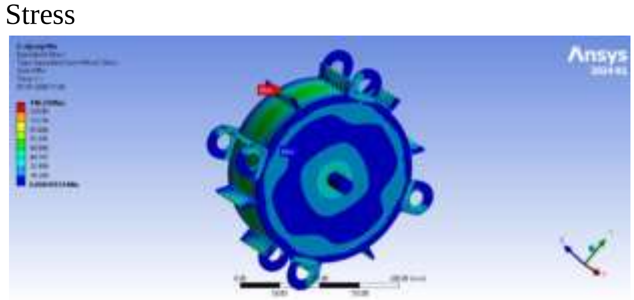
Strain



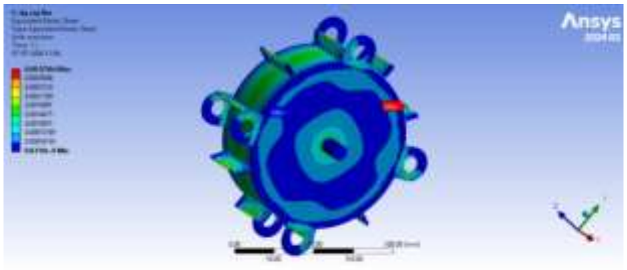
Zig zag fins
Az91d
Deformation



Stress

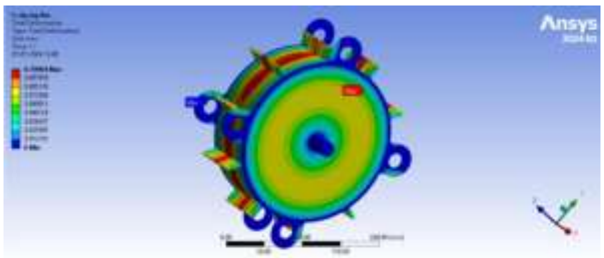


Strain

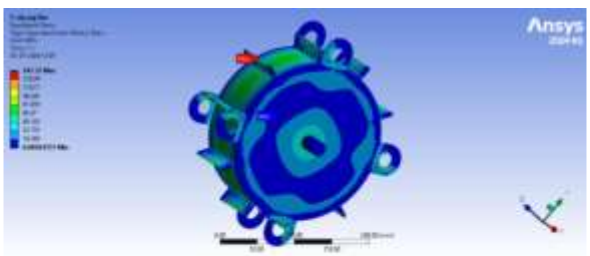


Al-6061

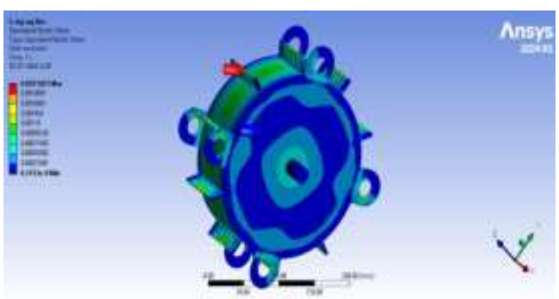
Deformation



Stress

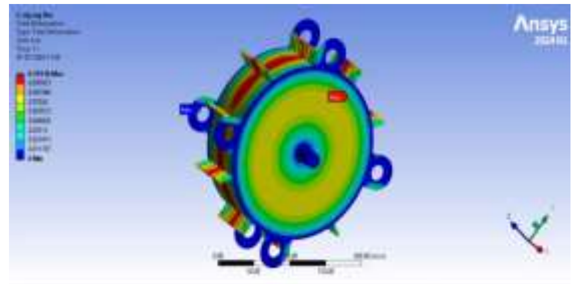


Strain

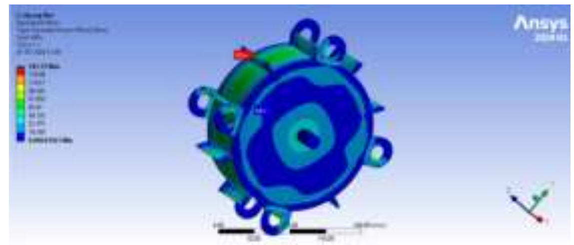


Al-7075

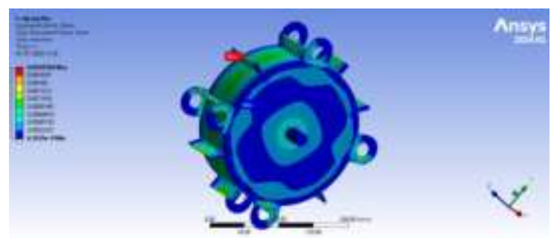
Deformation



Stress



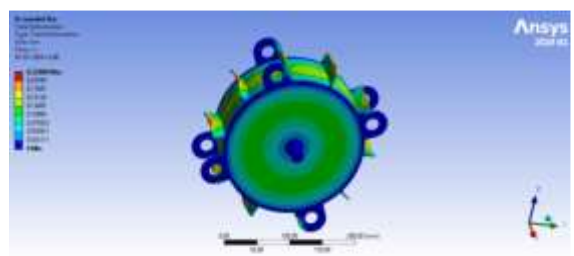
Strain



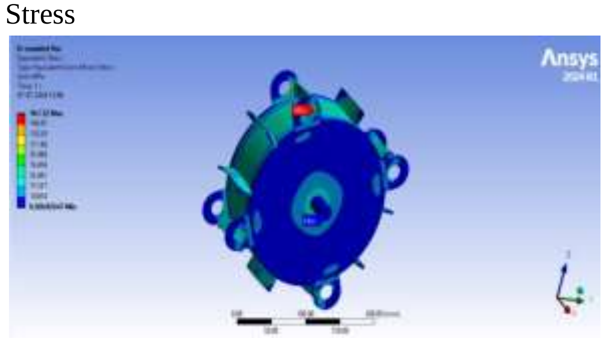
Rounded fins

Az91d

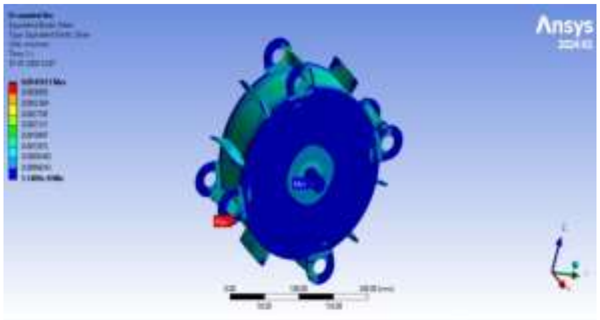
Deformation



Stress

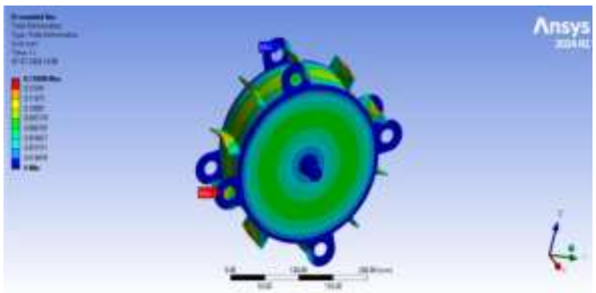


Strain

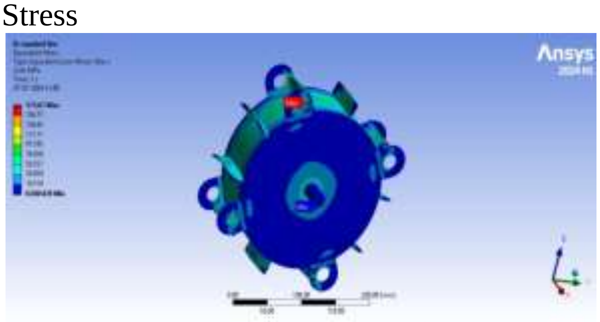


Al-6061

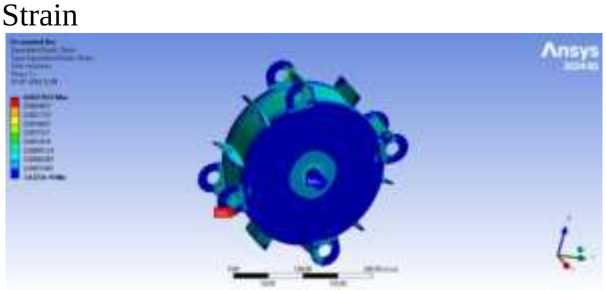
Deformation



Stress

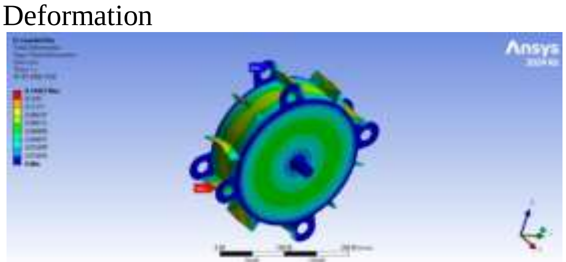


Strain

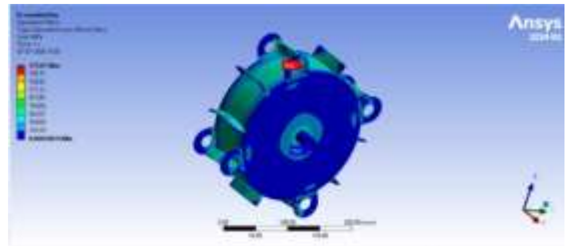


Al-7075

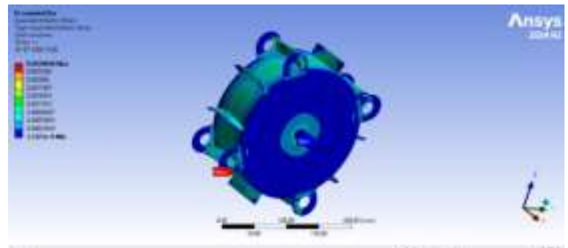
Deformation



Stress



Strain

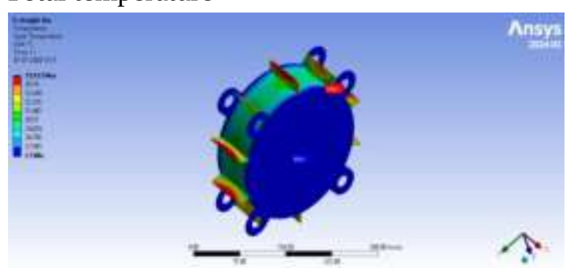


Thermal analysis

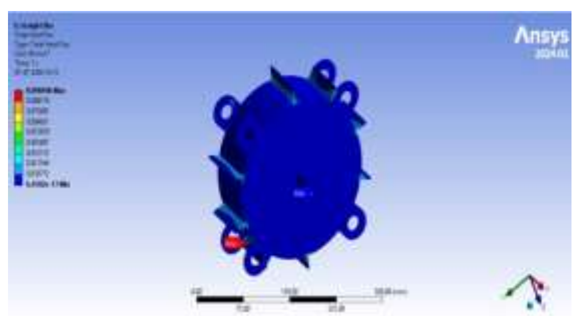
Straight fins

Az91d

Total temperature

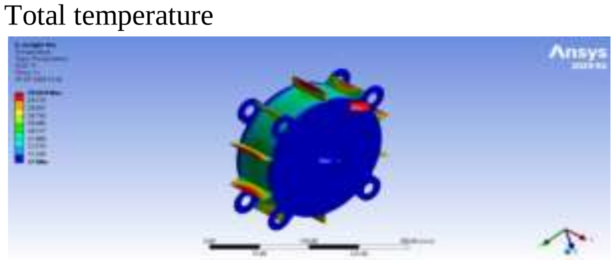


Heat flux

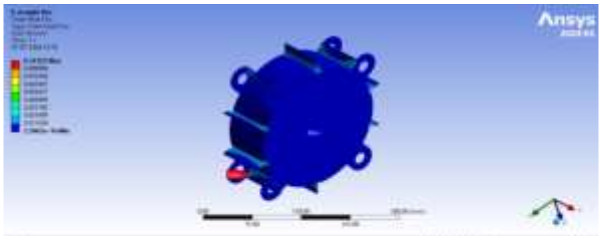


Al-6061

Total temperature

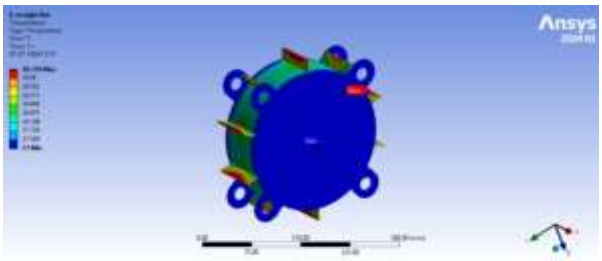


Heat flux

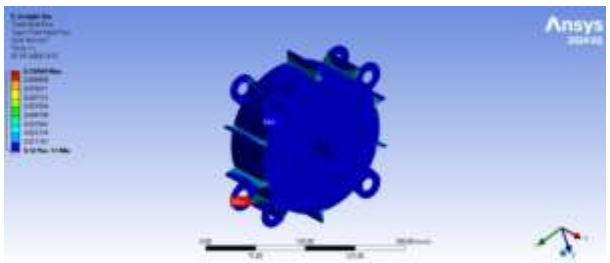


Al-7075

Total temperature



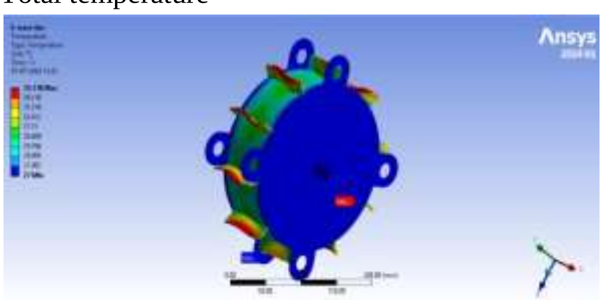
Heat flux



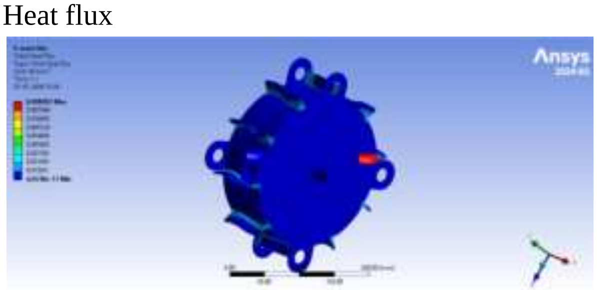
Wave fins

Az91d

Total temperature

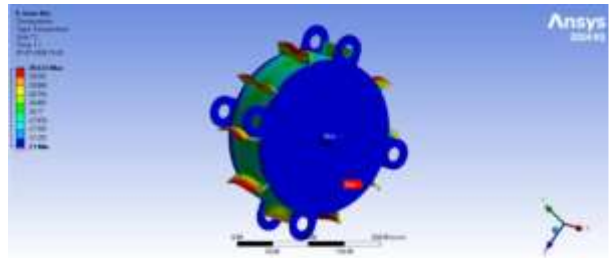


Heat flux

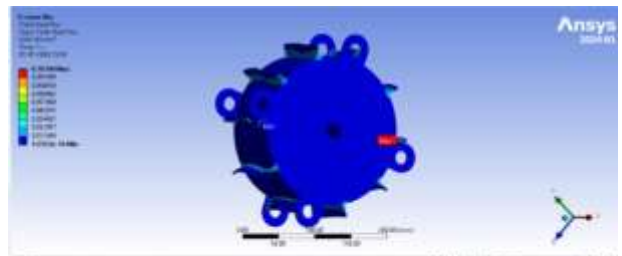


Al-6061

Total temperature

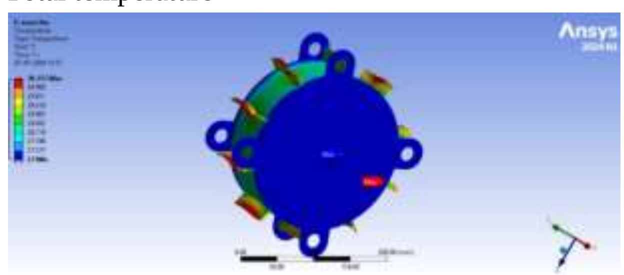


Heat flux

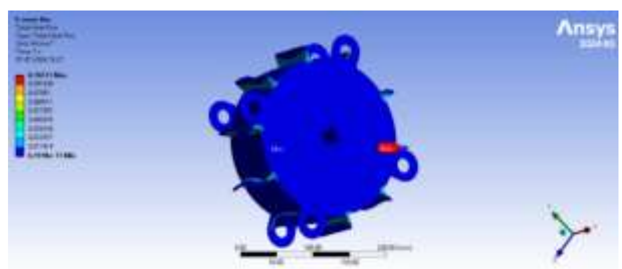


Al-7075

Total temperature



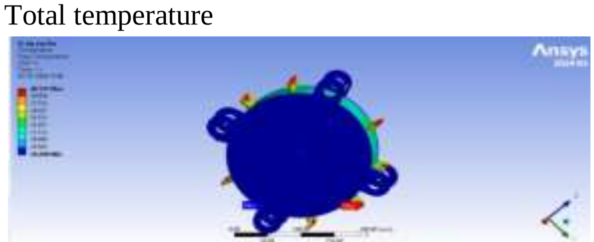
Heat flux



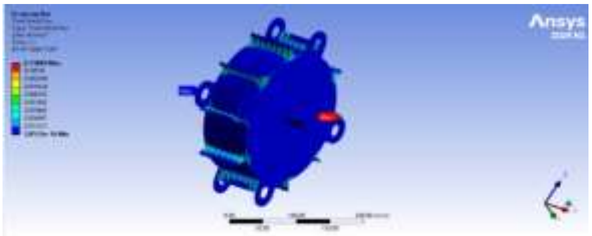
Zig zag fins

Az91d

Total temperature

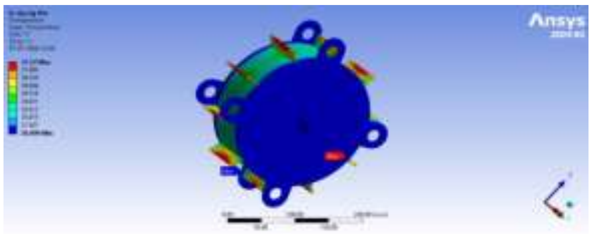


Heat flux

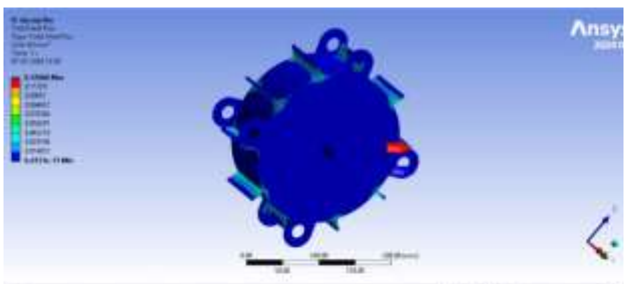


Al-6061

Total temperature

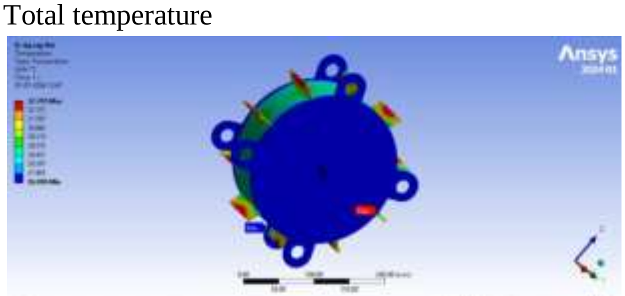


Heat flux

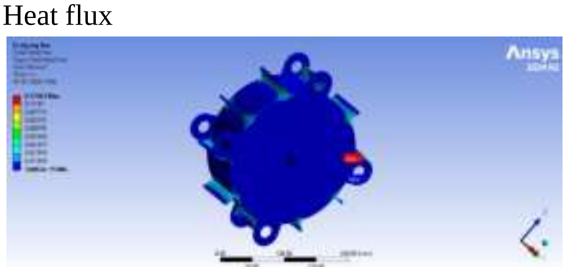


Al-7075

Total temperature



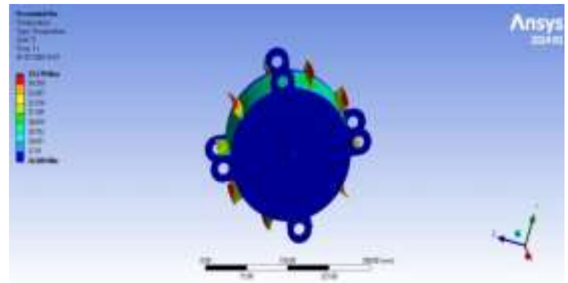
Heat flux



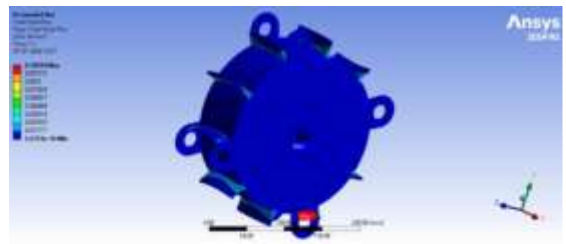
Rounded fins

Az91d

Total temperature

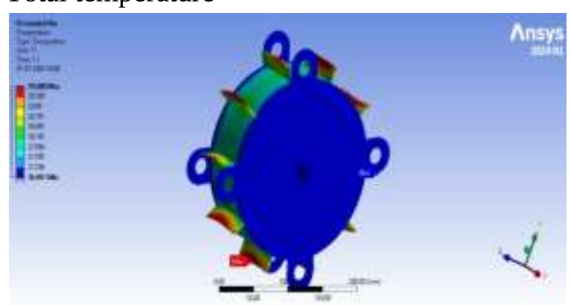


Heat flux

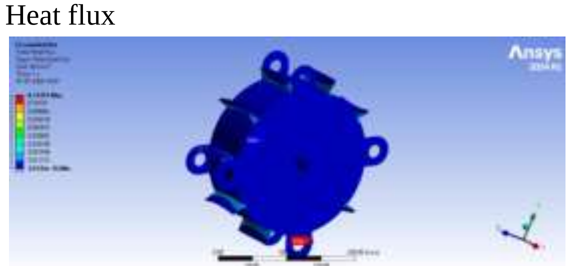


Al-6061

Total temperature

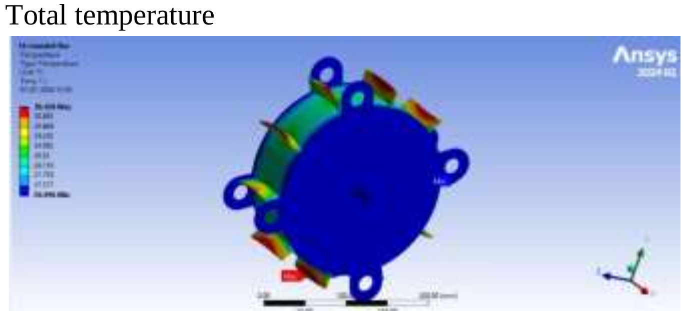


Heat flux

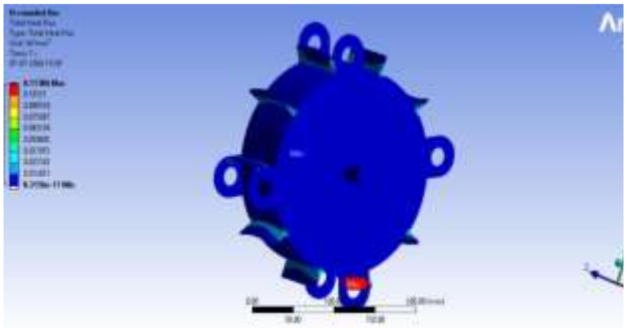


Al-7075

Total temperature



Heat flux



5. CONCLUSIONS

In this research design and analysed four electric motor housing fin configurations using AZ91D Magnesium Alloy, Aluminium 6061, and Aluminium 7075 through finite element simulations in ANSYS Workbench 2024 R1. Structural analysis confirmed that all designs satisfy the required strength criteria, with safety factors greater than unity. Aluminium 7075 exhibited the best mechanical performance due to its high yield strength and reduced deformation. Thermal analysis demonstrated that Aluminium 6061 consistently achieved the lowest operating temperatures and the highest heat flux across all fin geometries, confirming its superior heat dissipation capability.

Among the fin configurations, the zig-zag fin design exhibited the highest heat transfer performance, followed by the rounded, wave, and straight fin designs. Based on the combined structural and thermal analyses, the zig-zag fin geometry manufactured from Aluminium 6061 is recommended as the optimum solution for electric motor housing applications requiring efficient thermal management, while the zig-zag fin geometry made from Aluminium 7075 is recommended where structural durability is the primary design requirement. These findings demonstrate that optimizing both material selection and fin geometry can significantly improve the performance, reliability, and service life of electric motor housings used in electric vehicle and industrial applications.

REFERENCES

[1] X. Li et al., "Selecting Cooling Methods for Electric Motors," Applied Thermal Engineering, vol. 257, 2025.

[2] J. A. P. S. Raj et al., "Thermal Management Strategies and Power Ratings of Electric Vehicle Motors: A Comprehensive Review," Renewable and Sustainable Energy Reviews, vol. 192, 2024.

[3] S. Madhavan et al., "Thermal Management Analyses of Induction Motor Through Cooling System Optimization," Scientific Reports, vol. 13, 2023.

[4] X. Lv et al., "Thermal Management of Electric Motors Using Integrated Thermoelectric Cooling and Flat Heat Pipes," Case Studies in Thermal Engineering, vol. 66, 2025.

[5] D. Harinadh, P. Kumar Babu, and B. Kiran Kumar, "Heat Transfer Analysis of In-Wheel Electric Motor Housing with Different Cooling Fin Arrangement Using ANSYS," International Journal of Advance Scientific Research and Engineering Trends, vol. 6, no. 2, pp. 132–138, 2021.

[6] Y. Zhang et al., "Electric Motor Cooling Technologies for Electric Vehicles: A Review," Applied Thermal Engineering, 2023.

[7] O. Borsboom, M. Salazar, and T. Hofman, "Electric Motor Design Optimization: A Convex Surrogate Modeling Approach," 2022.

[8] A. Mousaei and S. A. Mohammadabadi, "Optimization of a Three-Phase Induction Motor

for Electric Vehicles Based on Hook–Jeeves Optimization Method," 2023.

[9] C. Bergfried et al., "Thermal Finite Element Model of an Electric Machine Cooled by Spray," 2024.

[10] R. Alamian et al., "High-Performance Rotor Cooling with Ducted Liquid in Completely Cold-Formed Modular Motor Shaft," 2025.

[11] A. Pesaran et al., "Review of Thermal Management Systems for Electric Vehicle Powertrain Applications," Renewable and Sustainable Energy Reviews, 2022.

[12] J. Kim, S. Lee, and H. Park, "Experimental and Numerical Investigation of Air-Cooled Electric Motor Housing," Applied Thermal Engineering, 2021.