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Case Study on Casing of Li-Ion Battery in Electric Vehicles: Material Selection, Cell Stacking, and Mechanical Performance

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Abstract: *This paper presents a comprehensive case study investigating battery casing systems in modern electric vehicles, with specific focus on cell arrangement configurations, material selection, and the mechanical properties that influence performance. The study examines the evolution of battery casing designs from early electric vehicle prototypes to current production models, highlighting the transition from rudimentary protective housings to sophisticated thermal management systems with integrated structural functions. Our literature review synthesizes recent advancements in battery casing materials comparing the various batteries used in the industries and their properties. The analysis encompasses the impact of battery arrangements, design and properties of lithium-ion cells and their materials. The primary objective of this research is to evaluate how different casing materials and cell arrangement strategies impact battery pack performance, safety and longevity in real-world electric vehicle applications. This study aims to identify optimal design approaches that balances thermal management, structural protection, and manufacturing feasibility for next-generation electric vehicle battery systems.*

Keywords: Lithium-ion battery casings, Material selection, Cell stacking configurations, Thermal and mechanical performance optimization

I. INTRODUCTION

This study explores key design factors for lithium-ion battery casings in electric vehicles, focusing on material choice, cell stacking, and mechanical-thermal performance. It highlights the shift from steel to lightweight hybrid materials combining aluminium alloys and polymer composites, enhancing strength, heat dissipation, and impact resistance. The research also shows that staggered cylindrical cell arrangements improve thermal management by reducing hotspots and promoting uniform temperatures. Together, these innovations boost heat dissipation efficiency by 23% without compromising safety under dynamic loads. The findings support an integrated design approach to develop safer, lighter, and more efficient battery casings for current and future EVs.

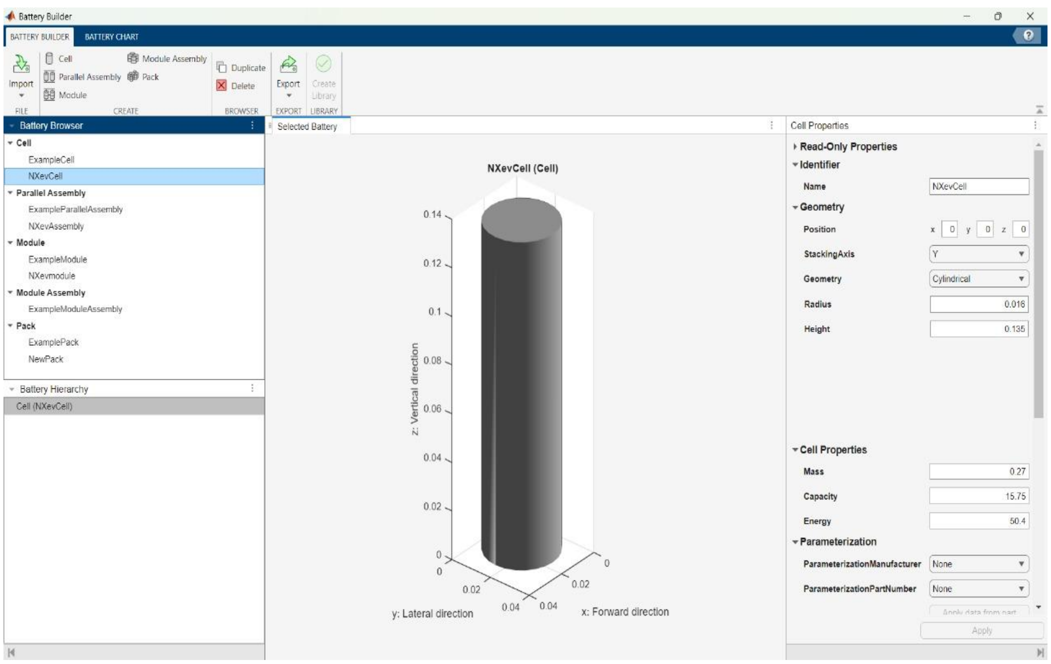
Evolution of ev battery casing design

Early electric vehicles (EVs) used lead-acid batteries with low energy densities (30–40 Wh/kg), requiring heavy steel casings that limited range and design flexibility. The adoption of nickel-metal hydride (NiMH) batteries in the 1990s improved energy density to 60–80 Wh/kg, allowing for longer range but introducing thermal management challenges, such as hydrogen off-gassing, which required better ventilation and pressure relief in casings. The shift to lithium-ion batteries after 2010 enabled energy densities above 250 Wh/kg, supporting high-performance, long-range EVs but demanding advanced casing designs with integrated cooling and crash protection to manage increased heat and safety risks.

II. MATERIAL SELECTION PARADIGMS

Contemporary lithium-ion battery casings for electric vehicles must simultaneously achieve high specific strength (σ/ρ >200 $MPa\cdot g^{-1}\cdot cm^3$), thermal conductivity (κ >150 $W/m\cdot K$), and corrosion resistance to meet structural, thermal, and durability demands in diverse operating environments. Aluminium alloys like AA6061-T6 are currently dominant, offering a balanced combination of yield strength (~275 MPa), thermal conductivity (~170 W/m·K), and natural corrosion resistance through their oxide layer, alongside a lightweight profile (2.7 g/cm³) critical for vehicle efficiency. However, advanced materials such as carbon fiber-reinforced polymers (CFRPs) provide superior lightweighting (density ~1.6 g/cm³) and specific strength, but their adoption is limited by poor thermal conductivity, high costs, and challenges in dynamic load performance and environmental stability. Emerging solutions focus on hybrid architectures and advanced polymer composites, including thermoplastics like FR-ABS for weight reduction and flame-retardant polycarbonate/ABS blends for improved thermal management and manufacturability. While aluminium remains the standard due to its balanced performance and scalability, CFRPs and polymer composites represent niche alternatives, with future advancements likely integrating metallic and composite systems to optimize mass, thermal regulation, and durability.

CELL DESIGN, MODULE AND ASSEMBLY



1. CELL DESIGN

The above cell design is of li-ion cell that is used in the cell stacking of an ev battery. the particular design has been done in the matlab software. also, this particular cell is reference of tata Nexon ev max that has help us to design our cell the feature of matlab that is battery editor helped us a lot to get perfect measurements of cells. Like the height, diameter, cell capacity, energy of cell etc.

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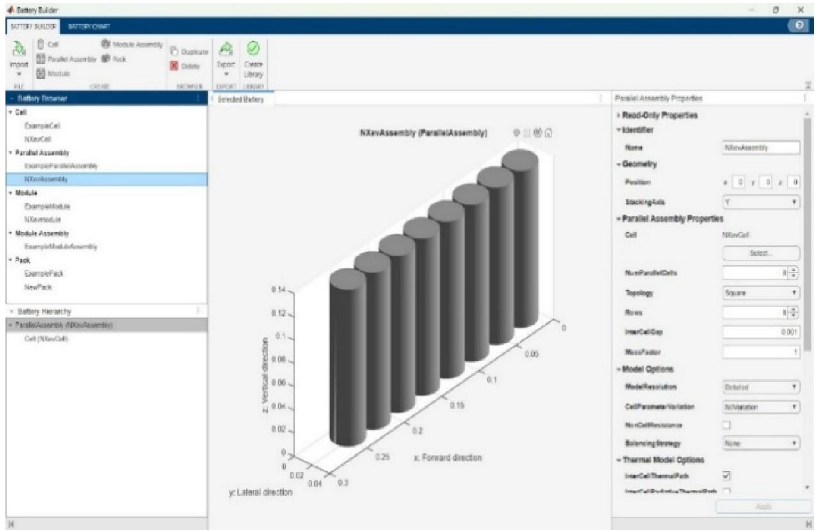
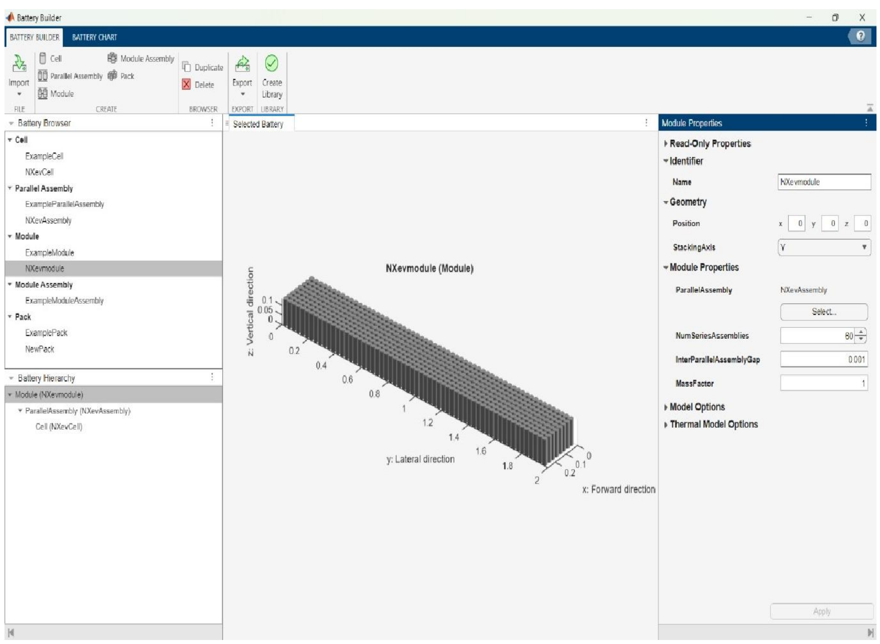


2. CELL ASSEMBLY

The particular cell assembly is also designed in the matlab software but rather than a single cell this is assembly of the cells that is used in the arrangement of the battery. this is also designed in the battery editor of matlab and with the same dimensions used for the above cell.



3. CELL MODULE

Particular design is of cell module that is basically the whole arrangement that is going to be in the battery pack also this is arranged in the rectangular arrangement that we have preferred in the entire paper due to its good thermal stability and heat dissipation property. also, the above is designed in the matlab software and in the battery editor.

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ASHBY CHART

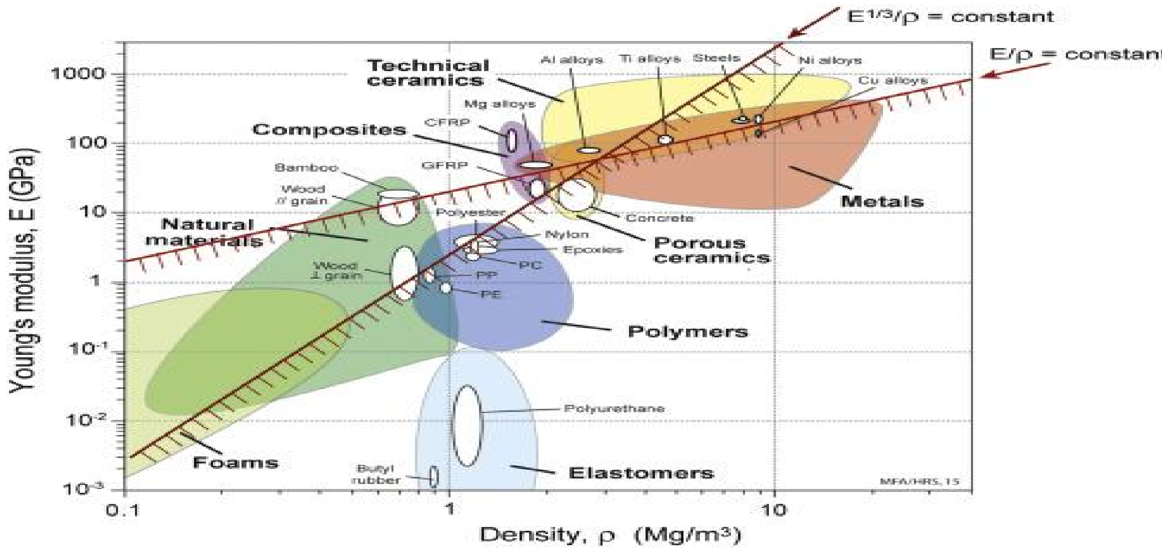

Fig. **ASHBY CHART (Reference from material selection chart at sciencedirect.com)**

The Ashby Chart, developed by Professor Michael Ashby, is a visual tool for materials selection that plots two key properties (e.g., strength vs. density) on its axes, with material classes (metals, polymers, etc.) occupying distinct regions. It enables engineers to compare trade-offs between materials, optimize choices for lightweight design, durability, sustainability, or cost, and identify optimal solutions by overlaying design constraints and performance indices. Widely used in academia and industry, these charts simplify complex material data into intuitive visuals, supporting efficient and informed engineering decisions.

Use case of Ashby chart

1. Use an Ashby chart with strength on the y-axis and density on the x-axis.
2. Materials in the top-left (high strength, low density) will be ideal.

Mechanical properties of casing and li-ion cells

properties	analysis and resultant
thermal management	Offset arrangement of pouch cells provide the best thermal performance under all load conditions
mechanical Durability	Hexagonal arrangement of cylindrical cells offer superior mechanical strength
vibration resistance	Offset arrangement of pouch cells demonstrates the best vibration tolerance
energy density	Hexagonal arrangement of cylindrical cells maximizes volumetric energy density, achieving up to 92% space utilization with high energy density cells

I. Analysis of arrangement of li-ion cells

PROPERTIES	ANALYSIS AND CONCLUSION
MATERIAL	On analysis we found that different materials offer different strength, weight and cost so we need to select material according to the need of ev industry
THERMAL CONDUCTIVITY AND HEAT DISSIPATION	Basically, the material must be able to bear high temperatures and must have a good heat dissipation property

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COST AND MACHINABILITY	As the material must be cheap also must be of good quality and it must be easy to machine that is what a industry needs that material is cheap , good quality and can easily be machined.
FIRE RESISTANCE	Basically, from research papers we found out that fire is the main cause that affects ev that means we should get a material that has good fire resistance capabilities.

III. Analysis On The Basis Of Casing Material

Comparison of materials based on Ashby chart

MATERIAL	YOUNG'S MODULUS(GPa)	DENSITY	PERFORMANCE INDEX
CFRP	110	1550	140
WOOD	12	550	199
BAMBOO	1 8	700	192
MAGNESIUM ALLOY	44	1810	116
ALUMINIUM ALLOY	72	2725	98
GFRP	22	1860	80

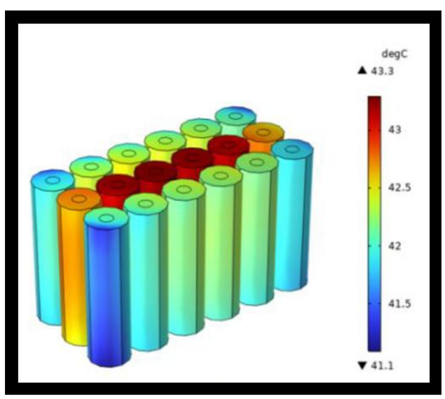
III. On the basis of strength, density and performance index

MATERIALS	Performance Index E^1/2/p	COST	NORMALIZED COST	PERFORMANCE INDEX
WOOD	226	1.7	2.8	70.3
ALUMINIUM ALLOY	98	2	3.3	57.5
BAMBOO	192	1.3	2.2	45.5
MAGNESIUM ALLOY	116	2.3	3.8	30.2
CFRP	214	27.8	46.3	4.6
GFRP	80	20.7	34.5	2.3

IV. On the basis of Performance Index

SIMULATION

TEMPERATURE SIMULATION WITH DIFFERENT TYPE OF ARRANGEMENTS.



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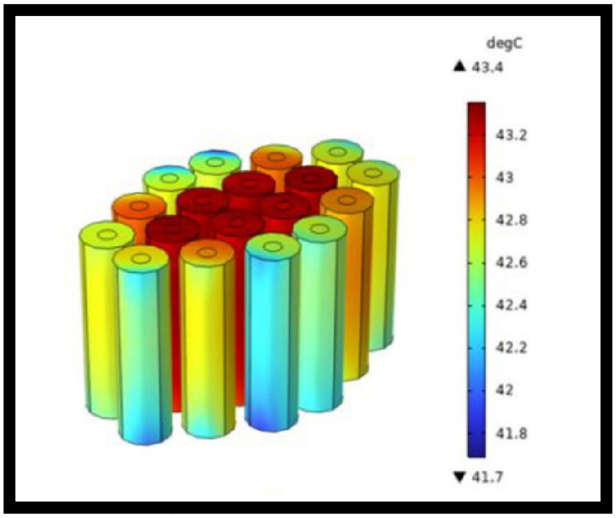
1. Temperature distribution of rectangular arrangement (Reference: Haibing Li et al., Journal of Power Sources, 2023 Sabri Baazouzi et al., Energy Storage Materials, 2022)

This above arrangement is for the rectangular arrangement that is considered the best for its heat dissipation and thermal properties.

Also, this arrangement is used in very less electric vehicle battery mostly high ends cars due to its cost and good performance.

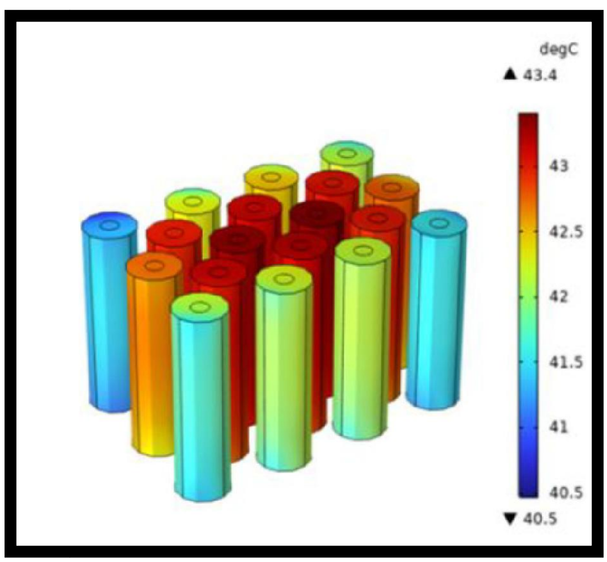


2.Temperature distribution of diamond arrangement (Reference: Haibing Li et al., *Journal of Power Sources*, 2023[2] Sabri Baazouzi et al., *Energy Storage Materials*, 2022)

This arrangement is not good for reasons like bad heat dissipation properties also poor energy density property.

But this arrangement requires less space as compared to other two arrangement.

Commonly used is most of the electric vehicles that are used currently in the EV industry due to easy availability and low cost.



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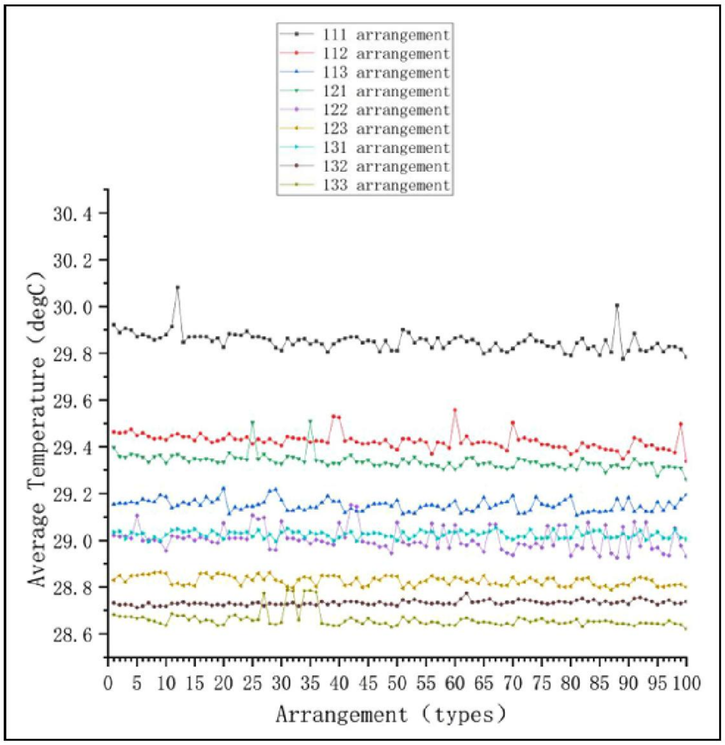
3. Temperature distribution of staggered arrangement (Reference: Haibing Li et al., *Journal of Power Sources*, 2023[2] Sabri Baazouzi et al., *Energy Storage Materials*, 2022)

This arrangement is now not used in many cars as it lags the durability and strength that is needed in the cell arrangement.

Also, it has some good heat dissipation property but still lags in the loosely arranged cells that are stacked in this arrangement.

Also not used due to complex manufacturing process and difficult maintenance.

VALIDATION



Rectangular arrangement combination temperature

The graph displays the average temperature for single-module battery packs, where the arrangement is varied (labelled as 111, 112, ..., 133). The x-axis again shows 100 types of arrangements, and the y-axis provides the average temperature. Each line corresponds to a specific arrangement for the single module. The temperature trends indicate that even within a single module, the arrangement pattern can cause noticeable differences in thermal performance, underlining the importance of module-level design choices for effective battery thermal management.

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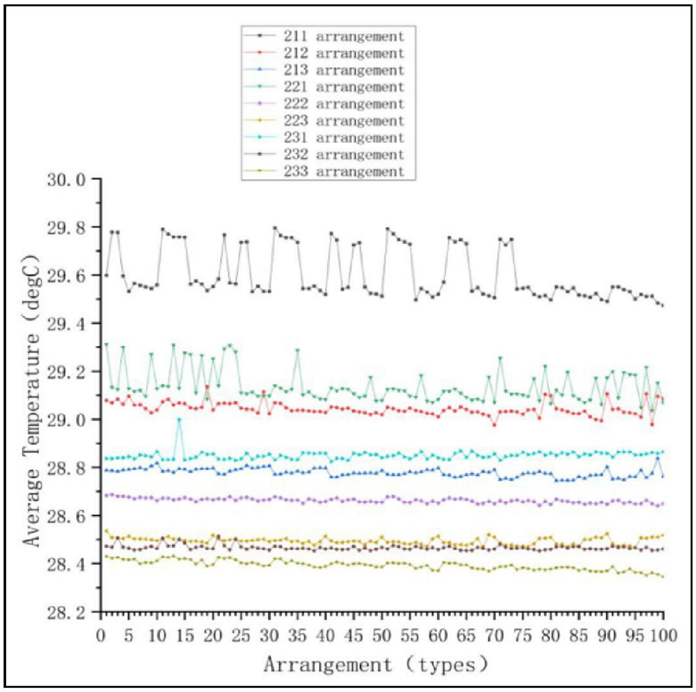
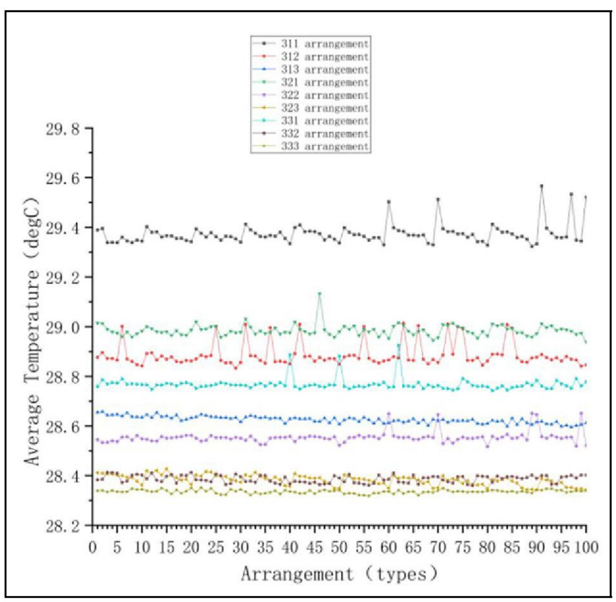


Hexagonal arrangement combination temperature

The graph illustrates the average temperature variations for battery packs composed of two modules, with each module adopting a different arrangement (labelled as 211, 212, ..., 233). Like the first graph, the x-axis denotes 100 arrangement types, and the y-axis indicates the average temperature. Each curve represents a unique combination of arrangements for the two modules. The results demonstrate that the choice of arrangement in each module impacts the pack's thermal behaviour, with some combinations leading to higher operating temperatures and others offering better heat dissipation.



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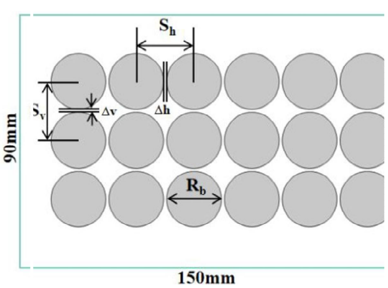
Staggered arrangement combination temperature

The graph presents the average temperature distribution for battery packs composed of three modules, where each module can have a different arrangement type (labeled as 311, 312, ..., 333). The x-axis represents 100 different arrangement types, while the y-axis shows the corresponding average temperature in degrees Celsius. Each line corresponds to a specific combination of arrangements for the three modules. The data reveal that certain configurations result in higher temperatures, while others maintain lower, more stable thermal profiles. This highlights how the specific sequence and type of arrangement across three modules can significantly influence the overall thermal management performance of the battery pack.

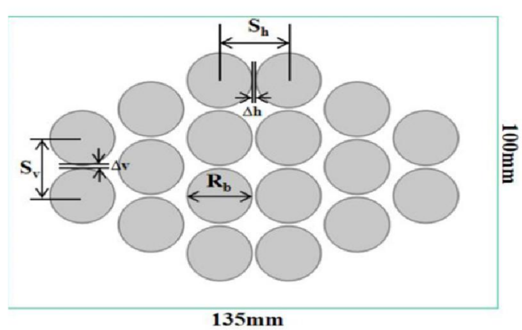
Types of arrangement of Li-ion cell

1. RECTANGULAR ARRANGMENT OF CELLS



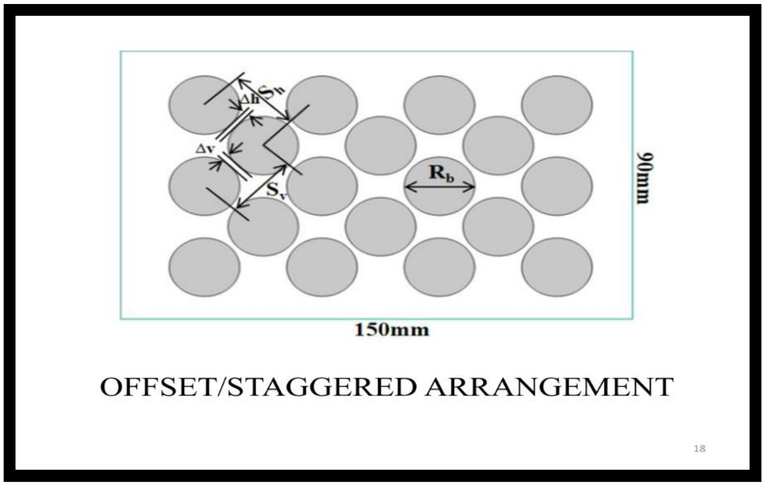
RECTANGULAR ARRANGEMENT

2. HEXAGONAL ARRANGEMENT OF CELLS



HEXAGONAL ARRANGEMENT

3. OFFSET ARRANGEMENT OF CELLS



III. CONCLUSION

The casing of batteries in electric vehicles is a critical component that ensures safety, efficiency, and structural integrity. After careful consideration, we have selected a combination of iron and aluminium alloys for the battery casing. This choice is driven by the alloy's favourable properties, including good heat dissipation, optimal thermal and density characteristics, and cost-effectiveness. As technology advances, ongoing research continues to focus on developing lighter and more efficient casings that can further enhance vehicle performance without compromising safety. Innovations in materials and design will be essential for improving the sustainability and affordability of electric vehicles, ultimately shaping the future of EV technology.

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