

2024

Report of Research Results

Thailand

a) TITLE: Advanced Safety Design and Analysis for Electric Motorcycles in Thailand

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c) Summary: Include the outline and conclusions of the research

The rapid adoption of electric motorcycles (e-MCs) in Thailand is a critical component of the national strategy to reduce carbon emissions and modernize urban transport. However, this transition introduces unique safety challenges, particularly regarding the vulnerability of centrally mounted lithium-ion batteries during accidents in Thailand's mixed-traffic environment. This study proposes a finite-element-based optimization framework to design a lightweight frame that prioritizes crash safety and battery protection.

Using LS-DYNA, ISO 13232 crash configurations were simulated and combined with a Sequential Response Surface Method (SRS) in LS-OPT. The objective was to minimize structural mass while adhering to strict constraints on battery intrusion and frame plastic strain. The optimization process achieved a 20.7% mass reduction, lowering the frame weight from 36.7 kg to 29.1 kg. Crucially, the design maintained battery intrusion below the 4 mm limit and significantly reduced plastic strains in both the frame and battery enclosure.

The design improvements were driven by reinforcing the support crossbar and tailoring the thickness of battery panels, which redistributed crash loads and enhanced enclosure integrity. To assess regulatory compliance, the optimized design was evaluated against UNECE Regulation No. 136 (UN R136). The frame satisfied all deformation- and strain-based prerequisites; however, crash impulses exceeded the UN R136 benchmark despite the battery enclosure remaining within the allowable deformation limits. These results demonstrate a practical pathway for balancing lightweighting with crash protection in e-MCs, providing a foundation for future Thai regulatory standards that integrate acceleration-based criteria.

d) Aim of Research

This study develops a regulation-informed optimization framework specifically tailored for the emerging e-MC market in Thailand. As electric two-wheelers become more prevalent on Thai roads, ensuring their structural integrity during collisions is paramount.

Finite element simulations of ISO 13232 crash scenarios were used to evaluate frame deformation and battery enclosure intrusion. A surrogate-based optimization method was then applied to minimize structural mass while strictly constraining safety-critical metrics. Post-optimization results were interpreted primarily with respect to UN R136. By embedding optimization outcomes within this regulatory context, the study provides a lightweight yet safety-focused design methodology essential for the next generation of electric motorcycles in Thailand.

e) Method of Research & Progression

The research methodology was based on regulation-informed optimization framework designed to balance the competing goals of lightweighting and crash safety in electric motorcycles (e-MCs). The investigation commenced with the development of a Finite Element (FE) model using LS-DYNA. The e-MC frame was modeled using STAM290GA steel with circular hollow sections, while the battery enclosure was constructed from ADC12 aluminum alloy panels. To simulate realistic loading conditions without the excessive computational cost of modeling individual battery cells, the internal battery mass was represented using homogenized foam properties. Strategic mass elements were

added to account for the 60 kg rider, 20 kg battery pack, and 10 kg motor assembly as shown in Figure 1. The model was meshed with a 5 mm element size and utilized defined contact interactions with a friction coefficient of 0.3 to ensure kinematic accuracy.

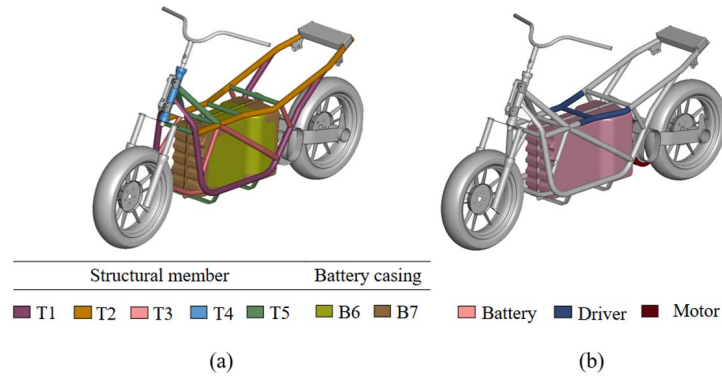


Fig. 1 (a) Structural frame and battery components (b) mass locations for dynamic simulation.

Following the model creation, the study selected crash scenarios based on the ISO 13232 standard, which covers the majority of urban motorcycle accidents. Three primary configurations were initially evaluated: a perpendicular side impact (Crash Type 143), an oblique frontal collision (Crash Type 114), and a frontal impact into a vehicle side (Crash Type 413). Frame failure and battery intrusion were analyzed in these scenarios to identify the governing parameters for the e-MC design. The final phase employed a Surrogate-Based Optimization approach using the Sequential Response Surface Method (SRSM) within LS-OPT as illustrated in Figure 2. The optimization objective was to minimize the total mass of the frame and battery enclosure subject to strict safety constraints. Specifically, battery intrusion was limited to a maximum of 4 mm to prevent short circuits, and plastic strain was constrained to avoid structural failure of eMC frame. The process utilized Latin Hypercube Sampling to map the design space, followed by iterative refinement until the mass reduction converged.

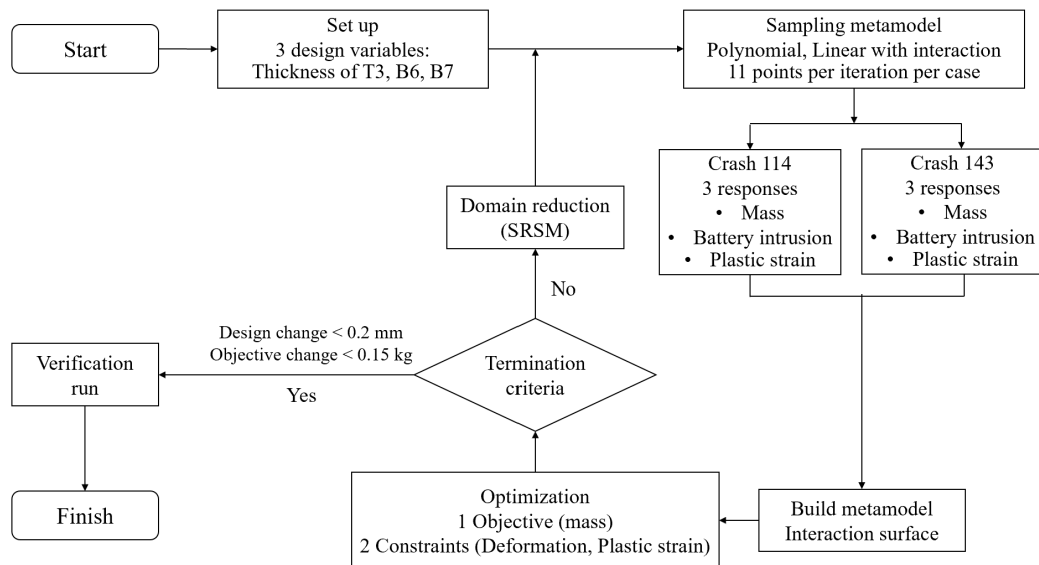


Fig. 2. Optimization workflow integrating LS-OPT with LS-DYNA crash simulations

f) Results of Research

The simulation analysis revealed that Crash Types 114 and 143 generated the most severe battery intrusion and plastic strain, as shown in Figure 3. The maximum battery intrusion occurred in Crash Type 114, reaching 9.23 mm, while a severe plastic strain of 3.63 was observed in Crash Type 143. These indicate a high risk of frame failure and battery short circuits, lead to the selection of these scenarios as the governing load cases for optimization. To facilitate the iterative design process, the researchers developed a simplified model of the opposing vehicle. This model was rigorously validated against full-scale simulations, achieving an error margin of less than 10% regarding

internal energy absorption while reducing computation time by over 60%, decreasing the duration from 5 hours to approximately 2 hours per run.

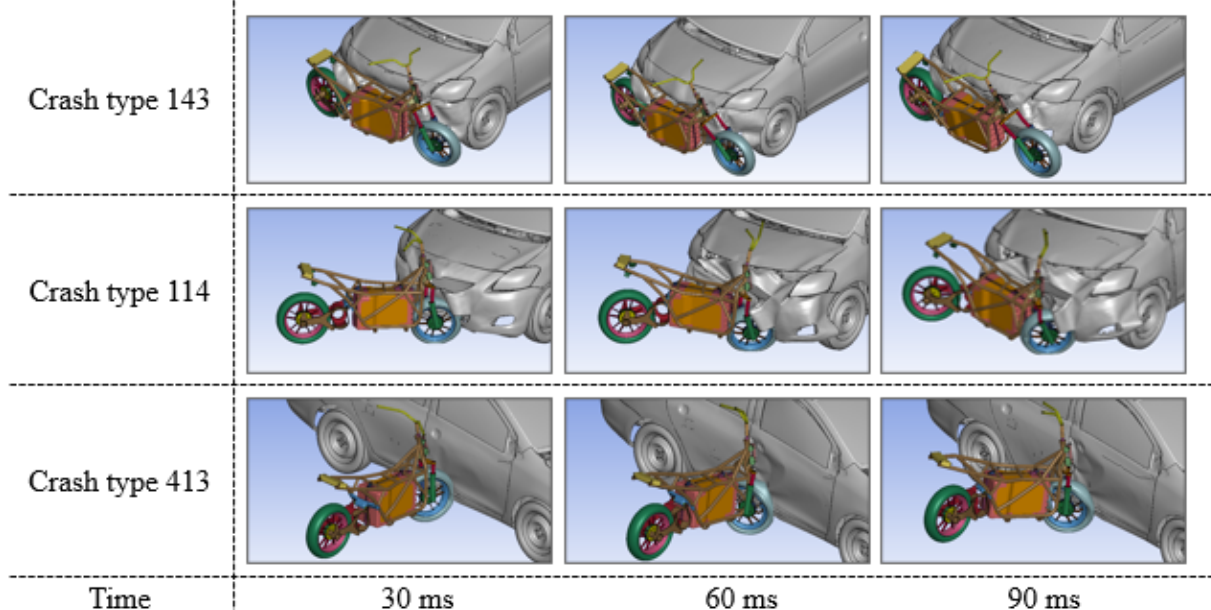


Fig 3. Overall crash patterns under Crash type 143, 114, and 413.

The application of the optimization framework successfully demonstrated that significant lightweighting could be achieved without compromising crashworthiness. Figure 4 presents the convergence history, illustrating the evolution of the three design variables: the wall thicknesses of battery panels B6 and B7, and the cross-sectional thickness of the battery support crossbar T3. The optimized design yielded a 20.7% reduction in total mass, lowering the combined weight of the frame and battery enclosure from 36.7 kg to 29.1 kg. This efficiency was not merely a result of material removal but rather a strategic redistribution of mass; the analysis identified critical load paths, leading to the reinforcement of the T3 crossbar while allowing for thickness reductions in less critical structural areas.

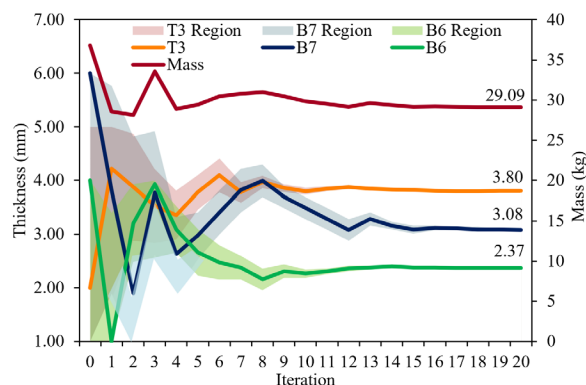


Fig 4. Convergence history of structural mass and design variables.

Mechanical metrics extracted from LS-DYNA are summarized in Table 1 and mapped against the safety intents of UN R136. In Crash type 114, the optimized design reduced battery intrusion ($\delta_{max, battery}$) by 58%, from 9.23 mm to 3.89 mm, thereby satisfying the 4.0 mm safety limit. Frame plastic strain decreased from 0.95 to 0.33 (Figure 5), while the casing deformation showed minimal inward displacement compared to the severe sidewall bulging of the baseline model. In Crash type 143, frame strain dropped from 3.63 to 0.40, precisely at the safety limit, while battery intrusion increased slightly from 1.82 mm to 2.87 mm, still within allowable limits. Both casing and frame plastic strains ($\epsilon_{max, battery} = 0.04$ and $\epsilon_{max, frame} = 0.4$) remained below critical thresholds, indicating low likelihood of breach or frame failure.

From a regulatory perspective, the design fully satisfied the deformation-based requirements of UN R136, ensuring that no electrolyte leakage or fire risks would stem from mechanical crushing. However, the study also calculated the inertial impulse experienced by the battery pack, recording values of 0.937 g·s and 1.099 g·s for the side and oblique impacts, respectively. These values

notably exceeded the standard UN R136 benchmark of 0.35 g·s. This finding highlights a critical nuance: while the enclosure successfully prevented external crushing, the internal cells may still be vulnerable to damage from high-g inertial shock, suggesting that structural stiffness alone may not fully guarantee electrical safety.

Table 1. Crash performance of baseline and optimized models relative to R136 safety criteria.

Safety Criteria	Simulated metric	Baseline Model (Crash type 143/ 114)	Optimized Model (Crash type 143/ 114)	Safety threshold
Prevent cell exposure / casing breach	$\delta_{max, battery}$ (mm)	1.82/ 9.23	2.87/ 3.89	4.0
Maintain frame integrity	$\epsilon_{max, frame}$	3.63/ 0.95	0.40/ 0.33	0.4
Maintain casing integrity	$\epsilon_{max, battery}$	0.02/ 0.15	0.04/ 0.02	0.4
Inertial exposure (REESS shock)	$I_{CG, battery}$ (g·s)	0.78/ 1.06	0.94/ 1.09	0.35

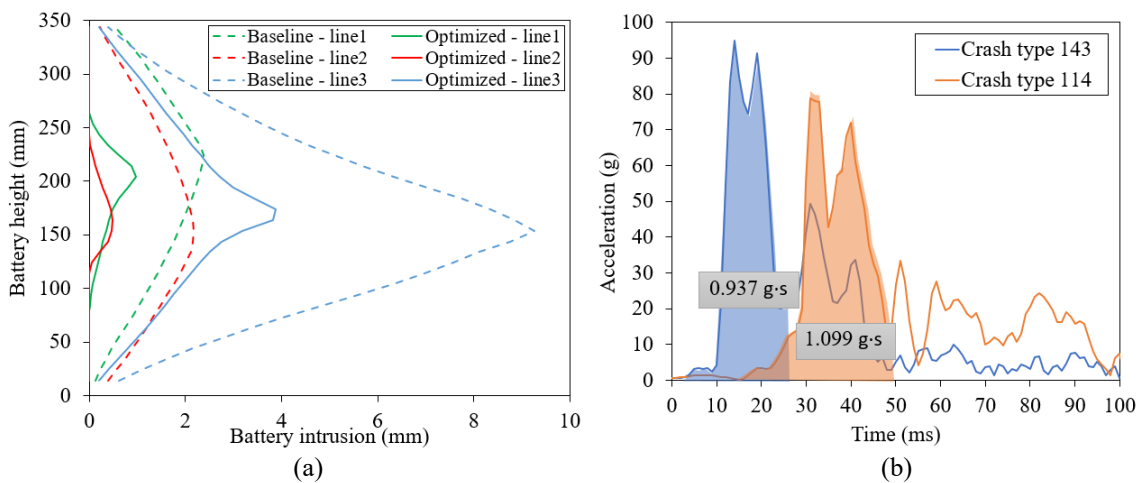


Fig 5. (a) Battery pack intrusion under Crash type 114 (b) battery acceleration time histories.

g) Future Areas to Take Note of, and Going Forward

Future research must bridge the gap between structural integrity and cell-level safety by investigating internal cell durability under the high inertial impulses observed in this study. Additionally, the scope of safety assessment should expand to include rider injury analysis through the integration of Finite Element dummy models to evaluate impact kinematics. Subsequent work must also evolve the optimization framework to include acceleration limits as active constraints—ensuring automated compliance with UN 38.3 shock standards—and validate these findings via physical sled testing.

h) Means of Official Announcement of Research Results

A journal paper entitled “Crashworthiness Optimization of Electric Motorcycle Frames and Battery Enclosure under ISO 13232 Impact Loading” has been prepared to be submitted to the International Journal of Impact Engineering (IF 2025: 5.70 (Scopus Q1)).