2019

MITSUI SUMITOMO INSURANCE WELFARE FOUNDATION RESEARCH GRANT 2019

Report of Research Results

Thailand

A. RESEARCH TITLE

Research Title	Passive Safety Performance of Electric Heavy Quadricycle (L7e) under Thailand Traffic Conditions

B. PRIMARY RESEARCHER

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C. SUMMARY

Summary: Include the outline and conclusions of the research

Future mobility inevitably involves eco-friendly electric vehicles due to progressing awareness about environmental pollution. An electric small four-wheeler, categorized by European Union as L7e so-called heavy quadricycle or microcar, is one of the solutions to sustainable urban mobility for personal transport. Nonetheless, quadricycles typically do not offer equivalent passive safety as larger passenger car models in case of accidents owing to the lack of energy absorption in the vehicle structure. This paper presents a proposed heavy quadricycle structure using plain weave carbon fibre-reinforced polymer in the passenger cell and aluminium alloy 6061-T6 in the crumple zone. The behaviors of electric heavy quadricycles under impact are simulated in accordance with the test guidelines of European New Car Assessment Programme using a nonlinear finite element analysis via LS-DYNA to examine structural crashworthiness and characteristics. Full-frontal crash with a rigid wall at 30 km/h to 50 km/h shows that the front crash box, longerons and subframes in the crumple zone can efficiently absorb energy under frontal crash up to 54.3%. The maximum damage in the structure occurs at the joints of the A-pillars and side beams to the front panel. The occupant safety space is safe under side collision by a 1350-kg moving deformable barrier at 50 km/h speed. However, the quadricycle tends to experience overturn from side crash due to the light vehicle's weight and high center of gravity. When overturning does not occur, the baseline structure is proved to be safe under side impact test up to 80 km/h. However, if the quadricycle is severely crashed, the side structure cannot efficiently dissipate the impact energy to other structural parts and thus supplementary energy dissipated members should be added to improve crashworthiness of the structure under side crash. Investigation on crash scenario with other vehicle types in which vehicle-mass, stiffness and geometry incompatibilities can cause more severe damage to the quadricycles should be further performed.

D. RESEARCH DETAILS

Aim of research

- *Social significance:* To suggest appropriate structural design to increase level of passive safety for small car in L7e category and to raise safety awareness as well as recommend proper practice of soon-to-be widespread electric heavy quadricycles.
- *Purpose of the research*: Apply finite element (FE) analysis to characterize the structural response of an L7e electric heavy quadricycle under collision based on Euro NCAP crash tests and Thailand regulations.

Method of Research & Progression

The detailed methodology is as follows;

1) Review regulations and past research on design and crashworthiness of L7e heavy quadricycle structure under different crash scenarios and crash test methods.
2) Prepare specimens (aluminum and composite materials) and perform tensile and impact tests to obtain both basic mechanical properties of materials and failure behavior under crash.
3) Validate a simplified finite element material model for composite structure in LS-DYNA compared with experimental results.
4) Create the baseline vehicle model of heavy quadricycle to analyse its crashworthiness under collision based on EURO NCAP test methods and crash scenario.
5) Modify and improve the FE model for accuracy and efficiency of the finite element model.
6) Analyse the FE results for deformation mechanism, crashworthiness of the vehicle structure and safety risks.
7) Investigate how to improve the vehicle structural design for passive safety of heavy quadricycle.
8) Summarize the research findings, prepare the final report and a technical paper to present in an international conference and submit a journal paper.

The research schedule for one-year plan is as shown in Table 1.

Table 1. Research plan and progression

Procedure	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
1. Review regulations and past research	■	■										
2. Prepare specimen and perform material testing for properties		■	■									
3. Validate finite element material model with results from tests			■									
4. Create baseline heavy quadricycle FE model in LS-DYNA				■	■							
5. Verify and improve the model for accuracy under crash simulation						■	■					
6. Analyse the heavy quadricycle under different crash scenario								■	■	■		
7. Suggest improvement of the vehecle design for passive safety										■	■	
8. Summarize research findings, prepare final report and technical manuscripts											■	■

Results of Research

I. Material testing

Material properties of woven E-glass with density of 400 g/m^2 (G400) and 600 g/m^2 (G600), plain weave carbon fiber (T700) and Aluminum 6061-T6, are obtained from tensile test specimens using Universal Testing Machine according to ASTM D3039, ASTM D3518 and ASTM D3410.

Table 2. Material properties for G400, G600, T700 and Al6061-T6

Property	G400	G600	T700	Al 6061-T6
Axial Young's modulus (GPa)	18.0	16.3	55.9	68.9
Transverse Young's modulus (GPa)	18.0	16.3	54.4	68.9
In-plane Shear Modulus (GPa)	2.2	2.9	4.2	26.0
Poisson's ratio	0.05	0.04	0.05	0.33
Axial tensile strength (MPa)	206.6	309.0	910.1	310
Axial compressive strength (MPa)	97.8	195.0	910.1	NA
Transverse tensile strength (MPa)	206.6	309.0	772.2	NA
Transverse compressive strength (MPa)	97.8	195.0	703.3	NA
Shear Strength (MPa)	27.5	27.9	131	207
Axial tensile failure strain (mm/mm)	0.012	0.020	0.0164	0.10
Shear failure strain (mm/mm)	0.024	0.030	0.030	NA

After material testing, the material for quadricycle crumple zone is selected as Al 6061-T6 due to its high energy absorption after yielding. The passenger compartment is selected as CFRP T700SC plain weave fabric which has the highest specific stiffness per unit weight.

II. Body design

The baseline quadricycle is 1.38 m wide, 2.27 m long and 1.26 m high. The structure is separated into 2 main parts, i.e., the front crumple zone made of aluminum alloy 6061-T6 with thickness of 2 mm and the passenger cell part made of T700SC plain weave fabric with thickness of 5 mm. The front crumple zone comprises of longeron and subframe parts while the passenger cell includes A-pillars, B-pillars, roof frame, front panel, rear panel, floor, and side beam as shown in Figure 1.

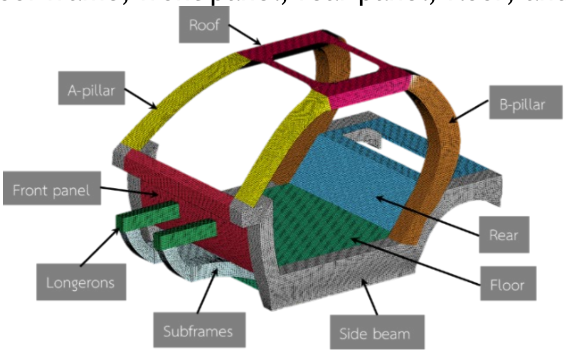
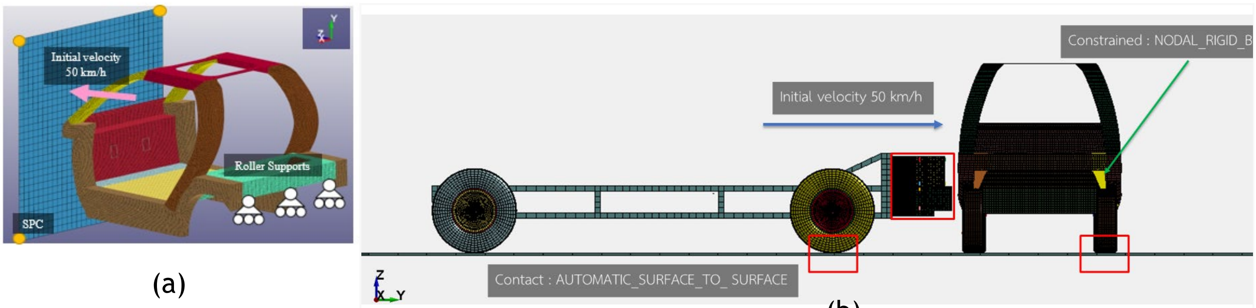


Figure 1. Baseline quadricycle components

III. Finite element modelling

The whole structure is meshed by using 4-node Belytshko-Tsay element with six degree-of-freedom (3 translations and 3 rotations) at each node. The element size is set to 10 mm. The model consists of 103,795 elements and 103,034 nodes. The total weight of the baseline quadricycle is 386 kg. Frontal and side crash scenario as shown in Figure 2 are investigated for energy absorption and damage behaviors.



(a) (b)

Figure 2 Crash scenario: Finite Element Analysis (a) Frontal crash to rigid wall (b) Side crash by MDB

IV. Results and discussions

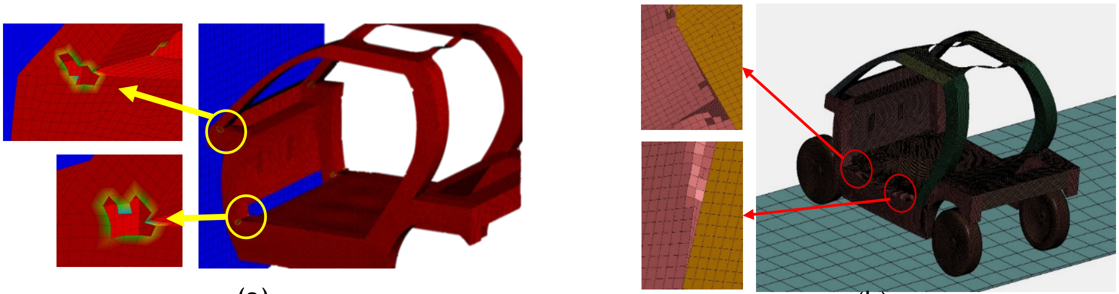
In the case of frontal impact when the crash speeds are 30 km/h and 40 km/h, the crumple zone can efficiently absorb all impact energy and the passenger compartment is intact. When the crash speed is at 50 km/h, the crumple zone is extremely damaged and not able to absorb all impact energy. In this case, damage of the passenger cell occurs at areas where the front panels connected to A-pillar and side beams. Table 3 listed the energy absorption of the crumple zone and specific energy absorption for each part (shown as numbers inside the brackets) at varying impact speeds. The crumple zone can absorb most of the impact energy when the crash is at a lower speed of less than 40 km/h. Although the longerons seem to absorb slightly higher energy than the subframe, when the parts are compared in terms of specific energy absorption, it is obvious that the EA of the longerons is more efficient.

Table 3. Energy absorption of the crumple zone.

Impact velocity	Impact energy (kJ)	Energy absorption, EA (kJ) [Specific energy absorption, kJ/kg]			Percent of EA
		Longerons	Subframe	Crumple zone	
30 km/h	12.1	5.0 [0.46]	3.8 [0.12]	8.8	72.5 %
40 km/h	22.0	8.0 [0.74]	7.5 [0.24]	15.5	70.0 %
50 km/h	33.8	10.6 [0.98]	7.9 [0.25]	18.3	54.8 %

Next, Euro NCAP side impact analysis is conducted by collision of a 1350-kg mobile deformable barrier (MDB) representing another passenger car crash to the side of the heavy quadricycle at 50 km/h. The CG of the baseline quadricycle is 599 mm from the floor when the ground clearance is at a typical value of 180 mm while the CG of the MDB is 500 mm. It is found that, at this height, overturning of the quadricycle may occur when it is crashed by the MDB trolley due to its small weight and its incompatibility with other passenger cars. The baseline model is then modified by lowering the ground clearance of the quadricycle to 150 and 130 mm. The quadricycle is analysed at crash speeds of 50 km/h and 80 km/h. The car with the ground clearance of 150 mm does not overturn when the MDB speed is 50 km/h but still overturns at high speed crash of 80 km/h. Nevertheless, the car does not experience overturning during crash when the ground clearance is lowered to 130 mm.

Figure 3 shows simulation results of damages of the quadricycle from frontal crash at 50 km/h and side crash at 50 km/h of the modified model. In the severe frontal impact, crumple zone is largely deformed, and some damages are noticed at A-pillar and the junction between the A-pillar and the floor. In the latter case of side crash, damages of the passenger cell are observed to first occur on the side beam. Afterward B-pillar collapses and the occupant's safety space is intruded. Energy dissipation to other parts via the structural parts is not as efficient as in the case of frontal crash. Redesign of the base structure with crossbeams to dissipate the side impact energy is therefore recommended.



(a) (b)

Figure 3 Passenger cell damages from crash test simulation at 50 km/h (a) Frontal crash (b) Side crash

V. Conclusions

This study presents finite element analysis of a heavy electric quadricycle with a CFRP passenger cell and aluminium crumple zone under frontal and side crash. It is shown that the front crumple zone can efficiently absorb impact energy from frontal crash and the car structure can efficiently distribute energy and guarantee safety of the occupant under Euro-NCAP front crash test with a rigid wall. When the baseline structure is side-crashed by an MDB representing another car, quadricycle is prone to overturn due to the light vehicle's weight and high center of gravity. Lowering ground clearance can be an option to avoid overturning of the quadricycle. When overturning does not occur, the baseline structure is proved to be safe under side impact test up to 80 km/h. However, if the quadricycle is severely crashed, the side structure cannot efficiently dissipate the impact energy to other structural parts and thus supplementary energy dissipated members should be added to improve crashworthiness of the structure under side crash. Further investigation on crash compatibility of quadricycle with other vehicles should also be examined in the future work.

Future Areas to Take Note of, and Going Forward

Investigation on crash scenario with other vehicle types in which vehicle-mass, stiffness and geometry incompatibilities can cause more severe damage to the quadricycles should be further performed.

E. MEANS OF OFFICIAL ANNOUNCEMENT OF RESEARCH RESULTS

International Conference (Presented, will be published in IOP database):

S Kongwat, S Jaroenjittakam, I Atchariyauthen, S Chaianan, P Jongpradist, Design for Crash Safety of Electric Heavy Quadricycle Structure, The 11th TSME International Conference on Mechanical Engineering, 1-4 December 2020, Ubon Ratchathani, Thailand.