

Study on Body Rigidity, Strength and Fatigue Performance for Carbon Fiber Reinforced Plastics Vehicles

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Abstract: Weight reduction of car is now main issue in order to increase vehicle fuel efficiency.

Among various lightweight materials, CFRP (Carbon Fiber Reinforced Plastics) is at the head because of superior stiffness and strength to weight ratio.

A durability performance development process of CFRP vehicle was studied, and applied to fuel cell concept car Intrado (code name HED9) in order to check compatibility of the process.

CFRP material was identified as a solution for satisfying weight lightening and performance of vehicle concurrently by comparing with general steel structure vehicle.

Keywords: Composite, Vehicle, Stiffness, Strength, Fatigue

1. Introduction

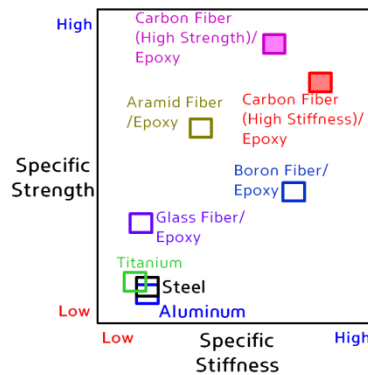


Figure 1. Characteristics of specific stiffness and strength

Weight reduction of car, related with increase of fuel efficiency and decrease of CO₂ emission gas, is main issues for vehicle industry. Use of light materials can be a good solution and CFRP (Carbon Fiber Reinforced Plastic) leads weight lightening trends in vehicle development. Figure 1 shows high specific stiffness and strength characteristics of CFRP comparing other materials.

2. Intrado (HED9) : CFRP Concept Car



Figure 2. Intrado Full car & BIW with chassis



Figure 3. Intrado BIW (skin & space frame)

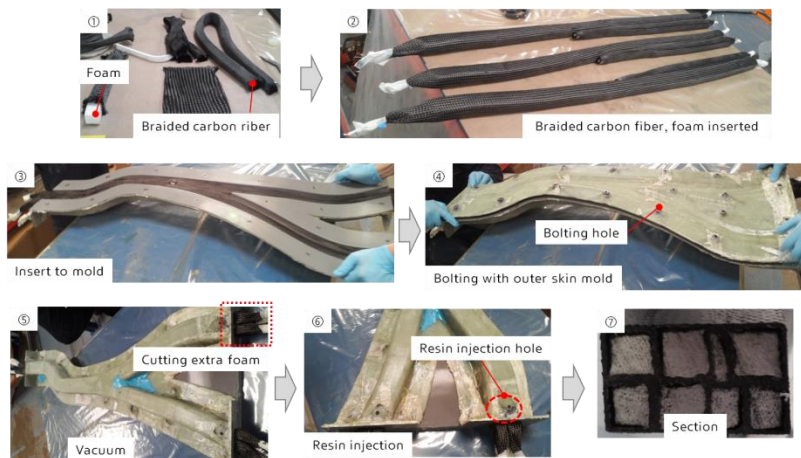


Figure 4. Making process of AXONTEX beam

Intrado(code name HED9), HMC fuel cell concept car, is debuted at 2014 Geneva motor show. Figure 2 and 3 show full car and BIW shape. CFRP space frame production process was used to make BIW of Intrado. Figure 4 shows making process of a base beam named AXONTEX BEAM. This process can make a closed box beam has multiple closed box beam at inner section.

3. Analytical study of body performances of CFRP vehicle

3.1 Modeling

Space frame of HED9 is made of braided carbon fiber. In order to express fiber orientation such as Figure 5, material properties from specimen tests are need. However, specimen extraction from beam structure is almost impossible. So unidirectional fiber specimens were made and material properties were generated such as Table.1. At this study, lay-up approach using unidirectional properties was used to express braided composite as Figure 6.

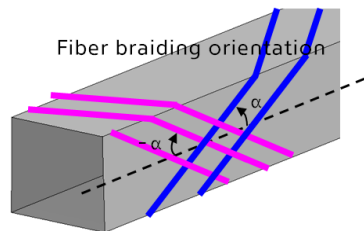


Figure 5. Fiber orientation of braided composite pipe

Table 1. Mechanical properties of unidirectional FRP

Stiffness		Strength (MPa)	
v_f	0.56	XT	1963
ρ	1.5 g/mm ³	XC	689
E1	117 GPa	YT	22
E2	9.5 GPa	YC	110
v_{12}	0.3	SL	54
G12	4.7 GPa	ST	56.7
Th	0.35 mm		

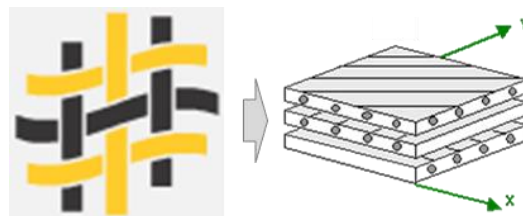


Figure 6. Analytical expression of fabric composite : Lamination

3.2 Static stiffness : Static torsional BIW stiffness

Torsional stiffness was checked for HED9 vehicle as Figure 7. BIW and trimmed body status models were used. Figure 8 shows the stiffness results. Stiffness is lower than HMC's Soul vehicles slightly, however specific stiffness is higher. Characteristics of stiffness and weight of Intrado were compared with EURO CARBODY entry vehicles. Body efficiency is almost same level, but stiffness is lower than with other composite vehicles. Because of concept car, detail design concept of high stiffness was not applied to Intrado. However weight reduction possibility was checked.

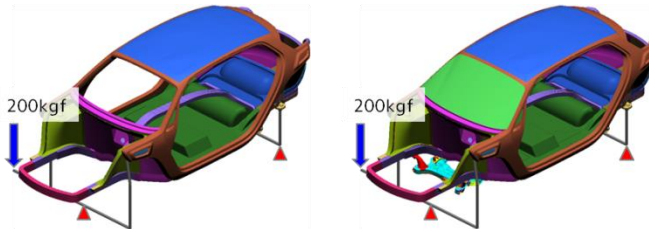


Figure 7. Torsional stiffness FEA model : BIW & trimmed body

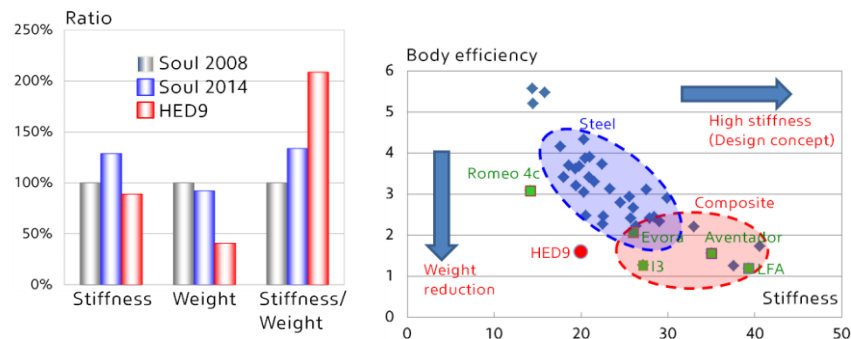


Figure 8. Torsional stiffness result : BIW & trimmed body

$$\text{Body efficiency} = \frac{\text{Weight}}{\text{Torsional stiffness} \times \text{Projection area of BIW}}$$

3.3 Strength : Roof strength

Roof strength is main performance to protect passenger from rollover of vehicle and that is one of IIHS (Insurance Institute for Highway Safety) TSP (Top Safety Pick) items. Figure 9 shows roof strength model and results. Similar with stiffness results, strength is less than Soul vehicles, but SWR (Strength to Weight Ratio : specific strength) is same level with Soul 2008.

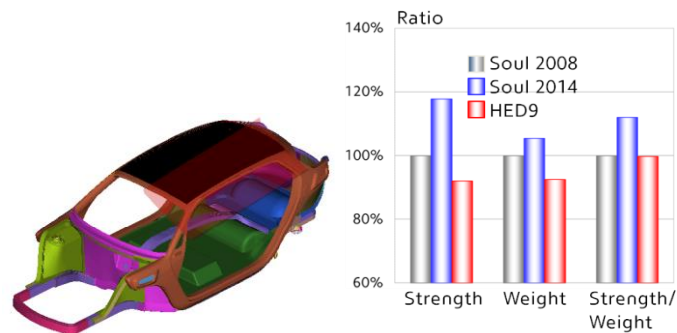


Figure 9. Roof strength FEA model & result

In order to express composite material failure during analysis, Hashin failure theory was used. Fiber/matrix and tension/compression failure modes can be shown at Figure 10.

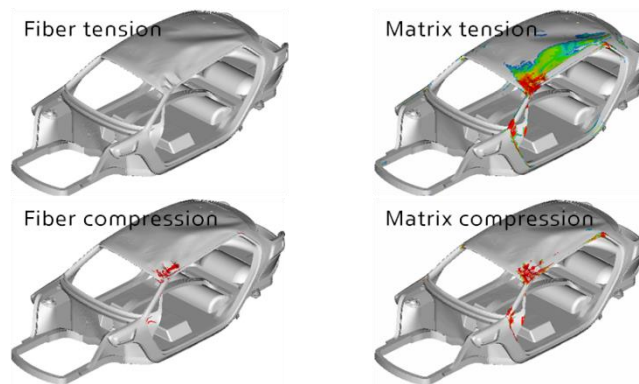


Figure 10. Composite failure modes

3.4 Durability : Belgian road fatigue

Figure 11 shows fatigue analysis model of Intrado. Because of lack of trim models, almost BIW status model was used. Figure 12 shows fatigue analysis process. In this study, ADMAS for load calculation, Abaqus for simulation of vehicle behavior, and fe-safe/Composite for life analysis were used. A fatigue characteristic of materials was not secured, so properties of similar material were used in fe-safe/Composite database. Figure 13 shows life contours at front strut mounting parts per each plies. Lamination angle difference at ②-③ and ⑥-⑦ is large, so delamination is predicted. However fatigue material properties is not compatible, this study is focused at understanding composite fatigue characteristics and analyzing methods.

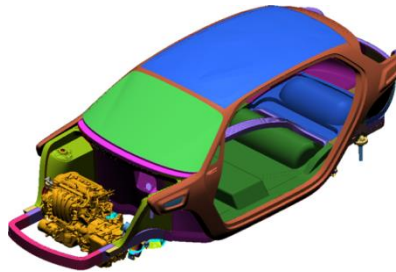


Figure 11. Belgian road fatigue FEA model

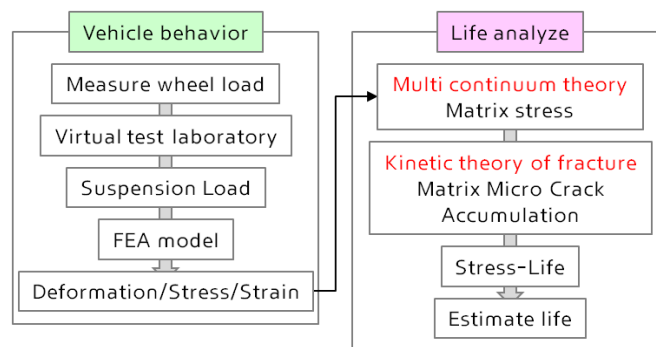


Figure 12. Belgian road fatigue FEA model

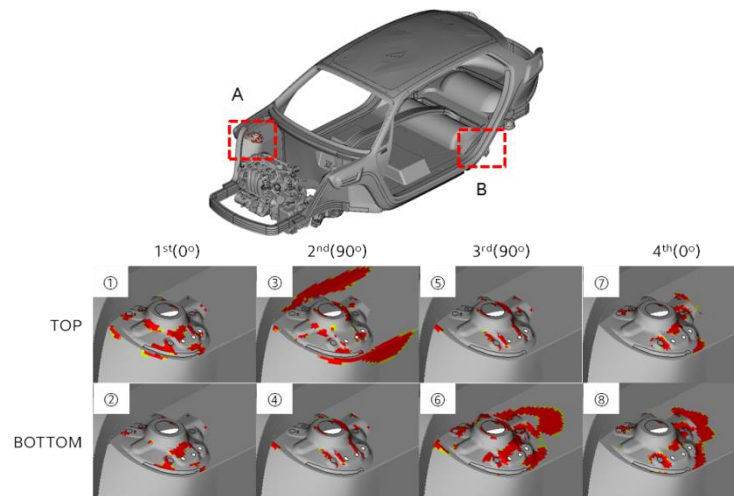


Figure 13. Fatigue result : Life contour at each ply

4. Conclusion

Analysis procedure for composite vehicle performance was considered such as stiffness, strength and fatigue. These processes were applied to INTRADO.

- 1) Effective design is possible using CFRP in the point of stiffness and strength
- 2) Composite fatigue failure characteristics were studied.

5. References

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2. Mechanics of Fibrous Composites, C.T. Herakovich, 1997.
3. fe-safe/Composite Theory Manual.