An Estimation of the Potential of Carbon Fiber Reinforced Thermoplastics for Car Weight Reduction

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Abstract

This paper presents an estimation of the potential for weight reduction of applying carbon fiber reinforced thermoplastics to an automotive body. More specifically, the weight change of a steel car body after a material substitution without reduction of body rigidity is evaluated. This is done by altering material properties and thickness of the selected parts of an original FEM model, LS-DYNA input file of the 1996 Dodge Neon developed by National Crash Analysis Center. The reduction in weight of the car body after the material substitution is estimated to be 30%.

Introduction

Carbon fiber reinforced thermoplastics (CFRTP) is now being developed as a next-generation material for lightweight mass-production car body. Although mechanical properties of CFRTP are inferior to those of carbon fiber reinforced thermosetting plastics (CFRTSP) which has already prevailed among aircraft structure [1]. Therefore, it is necessary to estimate how effective CFRTP application is as a lightweight car body solution.

Approach

A car body with steel monocoque (type STEEL) is set as a design basis. Steel parts consist of shell elements are subject to alter their material to CFRTP and most of such parts are categorized as main structure or outer panel. And we design CFRTP car body by altering material and thickness of these selected parts of type STEEL. Three types of CFRTP body model are made: type EFFICIENCY, type STIFFNESS and type STRENGTH. In order to assure that type EFFICIENCY is an appropriate design, body rigidity of four design types include type STEEL is derived from FEM analysis.

Material

QIUD, 40ISO and 20ISO are assigned as CFRTP materials. QIUD is quasi-isotropic laminates of unidirectional CF/PP tape with 50% fiber volume fraction (Vf). 40ISO is discontinuous CF/PP compound with 40% Vf and 20ISO is similar material with 20% Vf. Properties of these materials are shown in Table 1. A comparison of specific rigidity and strength with other materials is shown in Fig.1. These properties are based on target value of METI-NEDO project "Development of Sustainable Hyper Composite Materials Technology" [2] [3].

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14. ABSTRACT
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Table 1 Material properties of steel and CFRTP used in this study [4].

	Density	Young's modulus	Shear modulus	Strength
	g/cm^3	GPa	GPa	MPa
Steel	7.89	210	80.8	250-800
QIUD	1.5	47.6	18.4	586
Reference: UD		130	4.0	1600
40ISO	1.26	30	10.9	350
20ISO	1.08	17	6.2	300

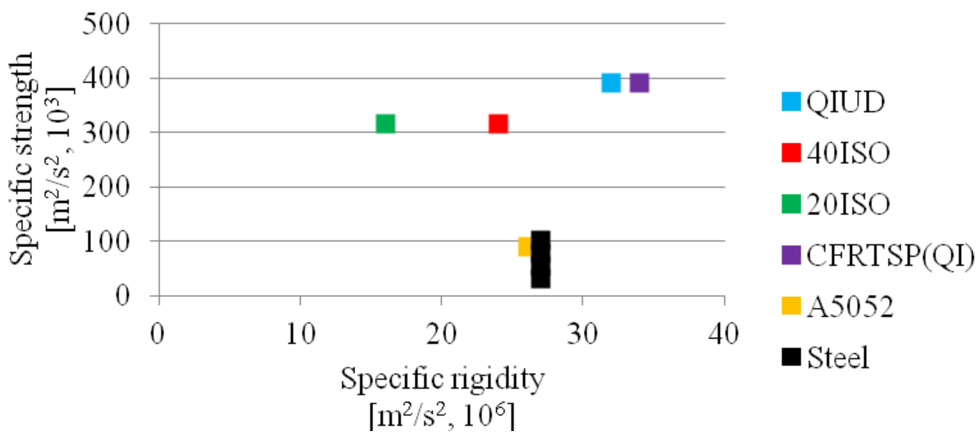


Fig.1 Comparison of specific rigidity and strength between CFRTP and other materials.

FEM Model

Basic FEM Model LS-DYNA input file of the 1996 Dodge Neon developed by National Crash Analysis Center is used as a design basis (Fig.2). Dodge Neon has 2.0 L engine and weighs 1,190 kg [5]. Basic FEM model (Fig.3) is built by omitting parts other than steel parts consist of shell elements and it weighs 310 kg.

Fig.2 Dodge Neon and finite element analytical model for LS-DYNA.

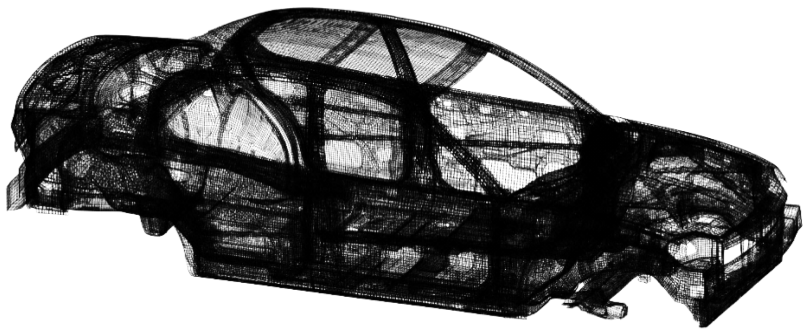


Fig.3 Basic FEM model consists of shell elements.

Designing Three Types of CFRTP Bodies QIUD, 40 ISO, 20ISO or otherwise steel is set as a material of each part included in this subset by considering the shape and usage of them. Basically, QIUD is used for structurally important parts and two types of ISOs for others. 40ISO and 20ISO are chosen according to whether rigidity is required or not. In order to build type EFFICIENCY, we set thickness of CFRTP parts by choosing the most appropriate formula for each part from Table 2. Also we build type STIFFNESS and type STRENGTH as extreme cases for comparison. Each CFRTP parts of type STIFFNESS have same or higher stiffness than original steel parts under three load types: tensile, bend and torsion. Similarly, each CFRTP parts of type STRENGTH have same or higher strength than original steel parts under three load types. As a consequence, weight and material breakdown of four design types is as shown in Table 3 and Fig.4. FEM analysis is performed with MARC distributed by MSC Software. Body rigidity is evaluated with two patterns of load condition as shown in Fig.5.

Table 2 Calculating formulas to derive thickness of CFRTP parts.

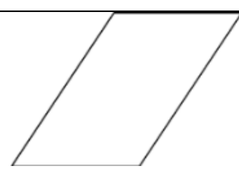
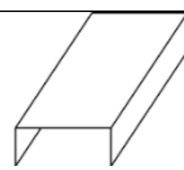
		 Plain	 Open	 Closed
Strength	Tension	$\propto \sigma t$	$\propto \sigma t$	$\propto \sigma t$
	Torsion	$\propto \sigma t^2$	$\propto \sigma t^2$	$\propto \sigma t$
	Bend	$\propto \sigma t^2$	$\propto \sigma t$	$\propto \sigma t$
Stiffness	Tension	$\propto Et$	$\propto Et$	$\propto Et$
	Torsion	$\propto Gt^3$	$\propto Gt^3$	$\propto Gt$
	Bend	$\propto Et^3$	$\propto Et$	$\propto Et$

Table 3 Weight comparison of four design types and breakdown of materials.

	Weight (kg)					Reduced weight (kg)
	Total	STEEL	QIUD	40ISO	20ISO	
STEEL	315.8	315.8	-	-	-	-
STIFFNESS	311.4	5.5	233.3	16.2	56.4	4.3
(%)		1.8%	76.3%	5.3%	18.4%	
EFFICIENCY	225.0	5.5	217.8	3.1	4.1	85.3
(%)		2.5%	96.8%	1.4%	1.8%	
STRENGTH	60.9	5.5	54.4	2.2	4.2	249.4
(%)		9.1%	89.4%	3.7%	6.9%	

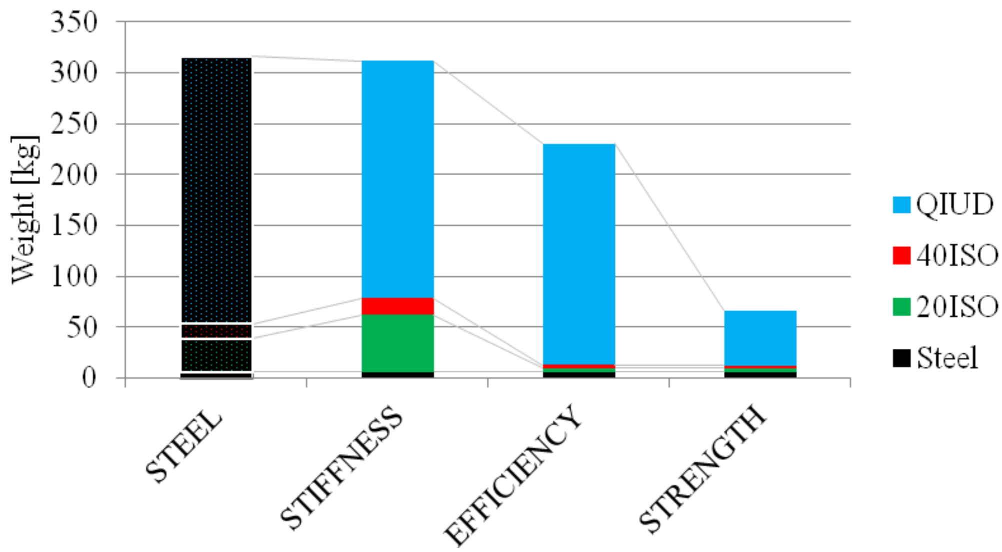


Fig.4 Weight comparison of four design types and breakdown of materials.

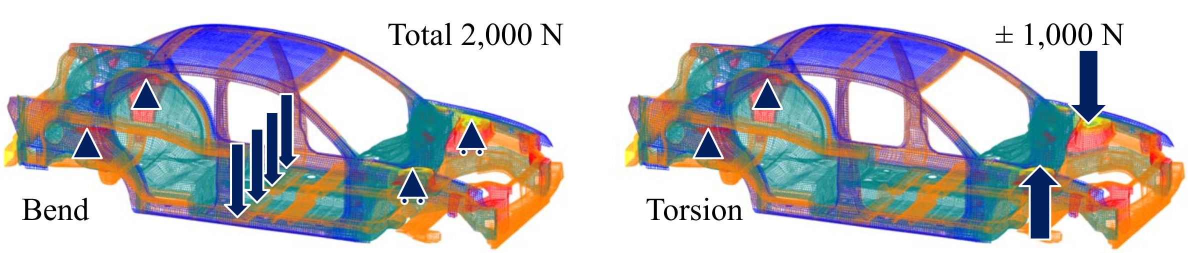


Fig.5 FEM conditions for bend and torsional analysis.

Result and Consideration of FEM Analysis

The Result of FEM Analysis is shown in Table 4. Fig.6 and Fig.7 are the deformation diagrams of two load conditions of type EFFICIENCY. According to the amount of deformation, type EFFICIENCY has enough body rigidity. This means type EFFICIENCY is an appropriate CFRTP body design. Type EFFICIENCY weighs 85 kg less than type STEEL. This weight difference accounts for 27% of main structure and outer panel which weighs 310 kg in total. Also this accounts for only 7.2% of total car weight, but weight reduction of main structure and outer panel will reduce other section's weight. Additionally, most part of steel monocoque body is in-plane loaded and rigidity is dominative. This means that high specific strength of CFRTP cannot be fully utilized. So a transformation of car structure itself into a structure suit for CFRTP will drastically reduce total car weight.

Table 4 Result of FEM analysis, amount of deformation.

	Bend	Torsion
	mm	deg
STEEL	1.42	0.094
STIFFNESS	0.49	0.028
EFFICIENCY	0.60	0.077
STRENGTH	4.77	0.503

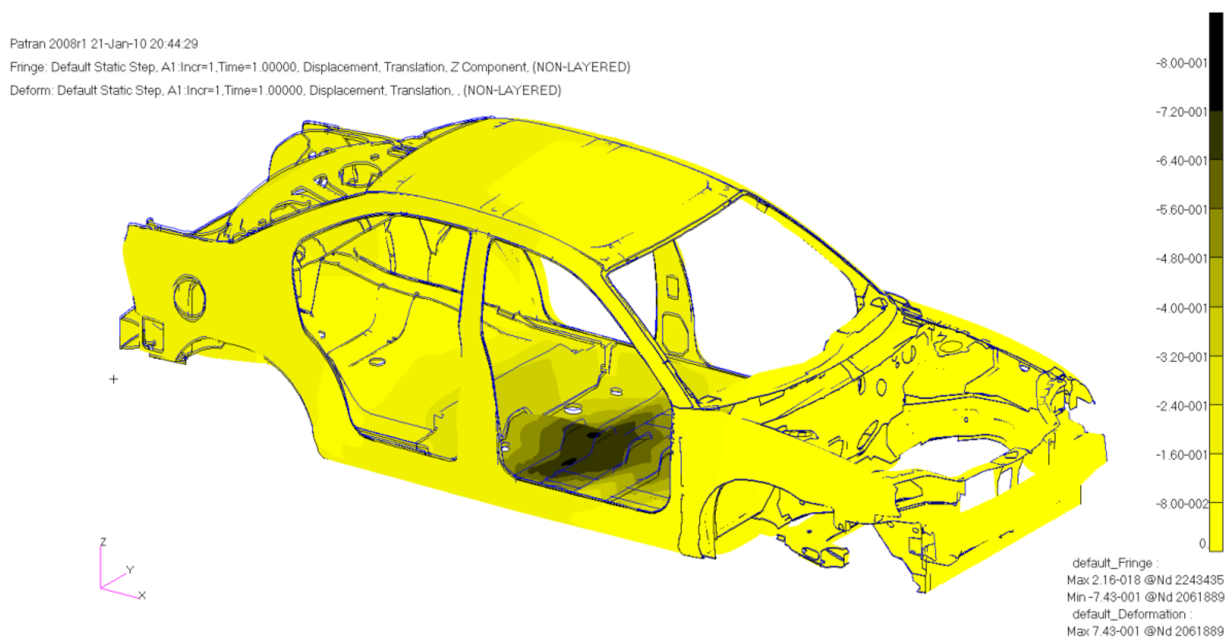


Fig.6 Type EFFICIENCY – Bend – Deformation.

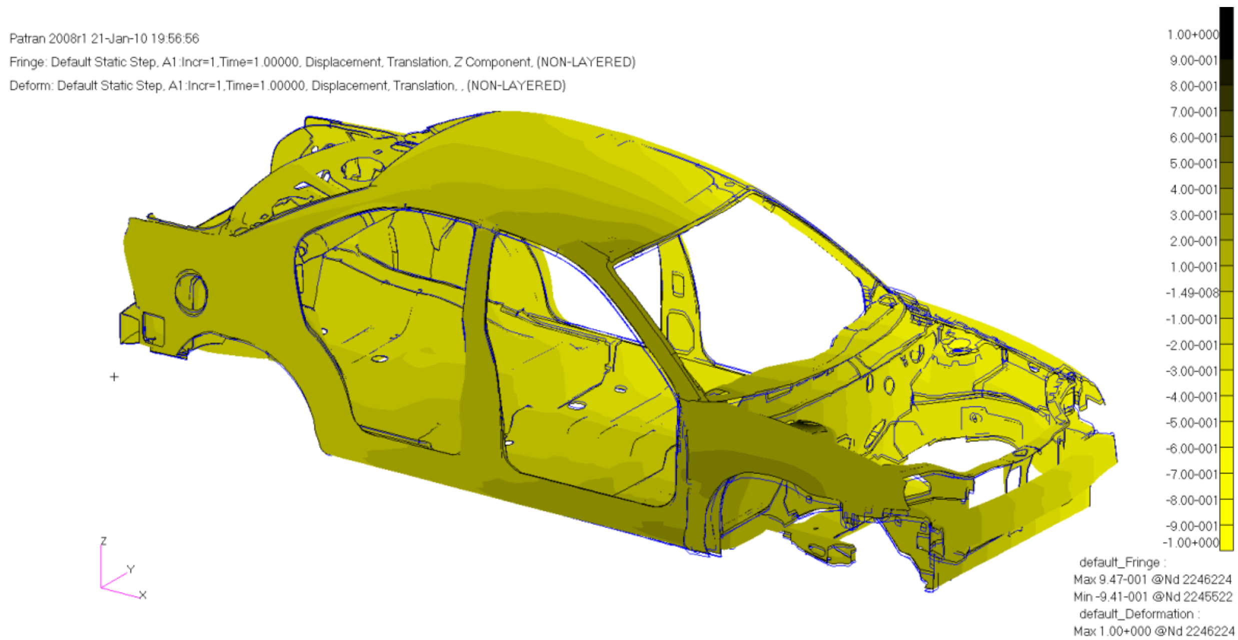


Fig.7 Type EFFICIENCY – Torsion – Deformation.

Conclusion

The potential for weight reduction of applying CFRTP to an automotive body is estimated.

- Type EFFICIENCY is appropriately designed as a CFRTP version of a Neon's body.
- Applying CFRTP by simple material substitution leads to 85 kg weight reduction.
- This weight accounts for 27% of original steel body and 7.2% of total car weight.
- A whole new car structure suit for CFRTP is necessary for further weight reduction.

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