LCA OF LIGHTWEIGHT VEHICLES BY USING CFRP FOR MASS-PRODUCED VEHICLES

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SUMMARY: Carbon fiber reinforced plastics (CFRP) have successfully been used in aerospace applications to replace heavier materials, because of their light weight, high strength and high rigidity. Although we strongly need the same benefits in automotive applications, the high price and the difficulty of the recycling process have inhibited its widespread use in the automotive industry. However, in the last few years, much work has been done in developing lower-cost CFRP. We thus used life cycle assessment (LCA) and calculated how much the environmental burden of conventional steel cars changed when we replaced steel with CFRP whose performance was proper for mass-produced passenger cars. As a result, the vehicle weight reduced by 36% and the energy consumption reduced by 15%. Therefore, we conclude that CFRP is good for reducing environmental burdens of passenger cars, and in addition that the flexible use of CFRP, in accordance with performance that car parts demand, is very important.

KEYWORDS: CFRP, energy intensity, environmental loads, LCA, lightweight, passenger vehicles

INTRODUCTION

Progress of fuel efficiency is strongly needed to reduce environmental burdens in the transport sector. Lightening vehicles is a necessary and important technology. As shown in Fig.1, carbon fiber reinforced plastics (CFRP) have been attracting attention as the best material for lightening. Japan has been the leader in the world in CFRP production, so gathering various data about CFRP is relatively easy. Energy intensity of PAN-based carbon fiber (CF) was calculated in 1997 [1]. It was 478 MJ/kg-CF. By using this value, we once considered how much vehicles lightened by CFRP reduced environmental burdens. Although fuel efficiency was actually improved by applying CFRP, life-cycle environmental burdens of CFRP vehicles were larger than those of conventional steel vehicles, because energy intensity of CFRP was much larger than that of steel at that time. Actually energy intensity of steel is 32 MJ/kg. However, since then we have calculated a new energy intensity of PAN-based CF [2]. It is 286 MJ/kg-CF. Although the new energy intensity is about half of the first one, it is still about nine times more than that of steel. We continued the study, taking into account which one was more eco-friendly, CFRP vehicles or steel vehicles by using the life cycle assessment (LCA). The CFRP we used in this study was not as highly-efficient as those for aircrafts, as it was produced for mass-produced vehicles.

INVENTORY ANALYISIS

Preset definition of LCA

(1) Goal of the study

To compare the life cycle environmental burden of a CFRP vehicle with that of a conventional steel vehicle.

(2) Products to be studied

Using statistics and catalogues from 2002, we set the specifications of the target car as a four-door sedan with the following features: front-placed gasoline engine, front-wheel drive, and automatic transmission. The weight was 1380 kg, and the engine displacement was 2000 cc.

(3) Functional unit and reference flow

Functional unit is "91,720 km", and a car that fulfills this condition is the reference flow.

(4) System boundaries

Three stages: Material production, vehicle production, use

(5) Elements of environmental burdens

Energy consumption and CO2 emission are mostly independent of place and time. This fact is very useful for conducting an LCI. In addition, the tendency of energy consumption and CO2 emission are quite similar. We, thus, only calculated the energy consumption in this study.

Energy intensity of CFRP for mass-produced vehicles

We used two types of CFRP in accordance with parts requirements. The first type was thermoplastic CFRP, which was used for the bodies, because they need good rigidity. The fiber volume fraction was 30%, and the matrix was polypropylene (PP), which is thermoplastic. The weight reduction potential of the CFRPP was 70% compared with steel on a specific rigidity basis. Energy intensity of carbon fiber (CF) and PP is 286 MJ/kg and 24 MJ/kg respectively (Table 1). Weight ratio between CF and PP was 0.462 : 0.538. Molding method is preform matched die, and its energy intensity is 10 MJ/kg. Therefore the energy intensity of the CFRP was 155 MJ/kg.

The second type was thermosetting CFRP, which was used for the chassis, because they need good strength. The fiber volume fraction was 60%, and the matrix was epoxy (EP), which is thermosetting. The weight reduction potential of the CFREP was 70% compared with steel on a specific strength basis. Energy intensity of EP is 76 MJ/kg. Weight ratio between CF and EP was 0.692 : 0.308. Molding method is resin transfer molding, and its energy intensity is 13 MJ/kg. Therefore the energy intensity of the CFRP was 234 MJ/kg.

Material production stage

We set the specification of the target vehicles as a four-door, sedan, gasoline engine, front engine and front-wheel drive, and automatic transmission from statistics in 2002. Vehicle weight was 1,380 kg, and engine displacement was 2,000 cc. In the case of steel vehicles, energy consumption for material production was 86,774 MJ. Next, in the case of CFRP vehicles, we considered how much we could lighten parts. We assumed a weight reduction ratio as follows; body and interior and exterior equipment were lightened by 60% due to replacing steel with CFRPP, engine system and driving and steering system were lightened by 30% and 5% respectively due to the secondary miniaturization, electric system, liquid and others did not lighten. Consequently steel and aluminum decreased 785 kg and 12 kg respectively, and CFRPP and CFREP increased 208 kg and 84 kg respectively. The total vehicle weight came to 881 kg and the weight reduction ratio was 36% (Table 2). Energy consumption for material production increased by 42,096 MJ compared with steel vehicles when yields of steel, aluminum, and CFRP were 61%, 64%, 60% respectively. As a result, the value of CFRP vehicles was 128,870 MJ.

Vehicle production stage

We set the energy consumption for vehicle production of steel vehicles as 21,406 MJ based on past studies. On the other hand, in the case of CFRP vehicles, use of CFRP resulted in a decrease in the number of parts and coatings. Moreover, using CFRP eliminates a shaping step as the final shape is almost incorporated during the making of the material. Thus energy consumption generally decreases when we make and assemble parts by using CFRP. In this study, we assumed that the energy consumption decreased by 20 %. This meant it was 17,125 MJ.

Use stage

The energy consumption during the use stage was the sum of gasoline consumption for traveling and energy for producing gasoline. First we considered the former value. From statistics, the annual mileage is 10,057 km and average use is 9.12 years, resulting in a total mileage of 91,720 km. As shown in Fig. 2, we calculated a relation between vehicle weight and real fuel efficiency using automobile catalogues and studies. It was,

$$Y=1/(6E\text{-}5*X+0.0174)$$

X: Vehicle weight (kg), Y: Real fuel efficiency (km/*l*)

Fuel efficiency of a steel vehicle weighing 1,380 kg was 9.98 km/*l*, and that of a CFRP vehicle weighing 881 kg was 14.23 km/*l*. Lifetime consumption of gasoline was 9,190 *l* and 6,446 *l* respectively, and calorific value is 35.17 MJ/*l*, resulting in the total consumption of 323,212 MJ and 226,706 MJ respectively.

Next we calculated the latter value. Energy for producing 1kg of gasoline is 6,756 kJ [3]. Density of gasoline is 0.75 kg/*l*, so the value per kg changes into 5,067 kJ/*l*. Energy for producing gasoline mentioned as 9,190 *l* and 6,446 *l* was 46,575 MJ and 32,668 MJ respectively. Therefore the energy consumption during the use stage of a conventional steel vehicle was 369,787 MJ and 259,374 MJ respectively.

Life cycle

Figure 3 shows the life-cycle energy consumption of a conventional steel vehicle and three CFRP vehicles. The energy intensity of CFRP is much larger than that of steel, so the energy consumption of a CFRP vehicle was larger during the material production stage. However, decrease of energy consumption during the use stage due to the weight reduction was much more effective, so replacing steel with CFRP had a total life-cycle energy consumption decrease. The reduction ratio was 15 %.

CONCLUSION

We conclude that CFRP vehicles are more eco-friendly than conventional steel vehicles. Reduction of energy intensity, improvement of yield and use of recycled CFRP due to improvement of production technique and mass production will develop CFRP vehicles into more eco-friendly vehicles. We want to study the proposed benefits of this effect from now on.

ACKNOWLEDGMENTS

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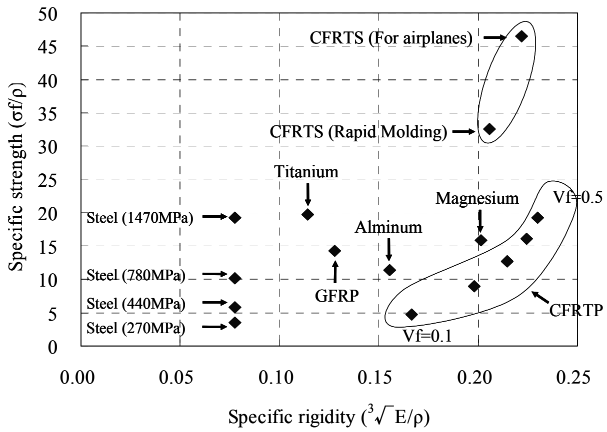

Fig. 1 Specific rigidity and specific strength of several materials

Table 1 Energy intensity of materials

	Energy intensity [MJ/kg]
Steel	32
CF	286
CFRPP*1	155
CFREP*2	234

*1: Vf = 30%, *2: Vf = 60%

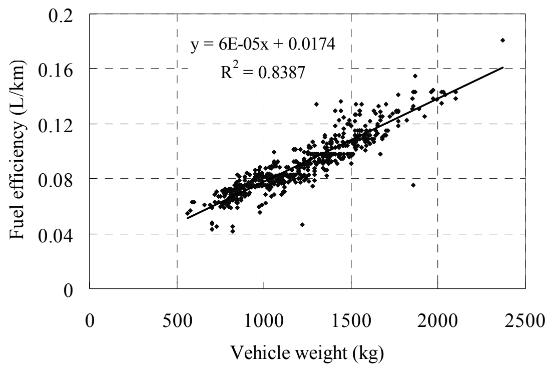

Fig. 2 Relation between vehicle weight and real fuel efficiency

Table 2 Parts weight before and after lightened

Parts	Weight before lightened [kg]	Weight after lightened [kg]	Weight reduction ratio [%]
Body	475.04	202.99	57.3
Interior & Exterior	223.49	183.52	17.9
Chassis	278.49	152.69	45.2
Engine System	194.39	136.08	30.0
Driving & steering system	48.62	46.20	5.0
Electric system	117.69	117.69	0.0
Liquid, Others	42.26	42.26	0.0
Total	1380.00	881.44	36.1

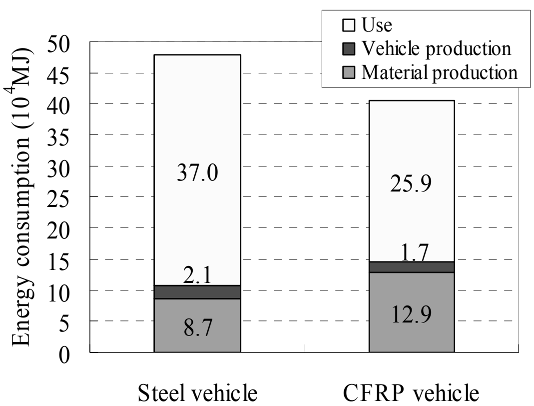

Fig. 3 Energy consumption during the life cycle