Strategies and Technological Challenges for Realizing Lightweight Mass Production Automobile by using CFRTP

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Abstract

To realize ultra-lightweight mass production automobile by CFRP (carbon fiber reinforced plastics), we have to solve the problems concerning cost, manufacturing, recycling, etc. In this paper, we will introduce Japanese national project which started at 2008 fiscal year to solve these problems by using CFRTP (carbon fiber reinforced thermoplastics).

Introduction

Although the energy efficiency of internal combustion engine is as poor as about one third of EV (electric vehicle), by virtue of the easiness in storage of liquid fuels, most of the energy used for transportation is oil as shown in Fig.1. Consequently, sixty percent of the world's oil consumption has been just burned in the transportation sector as shown in Fig.2. Before full-scale motorization in developing countries, widespread use of drastic energy-saving technology such as EVs and ultra-lightweight vehicles is indispensable.

Fig.3 shows an energy consumption structure of Japanese transport sector, and most of energy is consumed by passenger automobiles and trucks. And then spread of EV is restricted by secondary batteries and motors since they are heavy, expensive and using rare metals. Weight lightening of vehicles is thus effective not only to just improve energy efficiency but also to reduce mass of secondary battery and motor. Hence, weight lightening technology of automotive body is effective to an immediate energy saving of internal combustion engine vehicles but also early spread of EVs.

2008	Population	Total Primary Energy Supply	Total Final Energy Consumption
OECD	1190 million	4.56 toe/capita	3.11 toe/capita
Non-OECD	5498 million	1.24 toe/capita	0.86 toe/capita

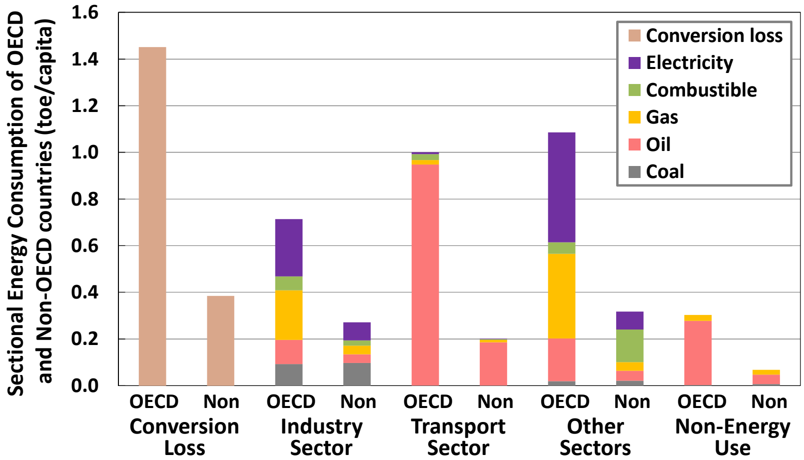

Fig.1 Sectional energy consumption of OECD and non-OECD countries. (data source: IEA statistics[1])

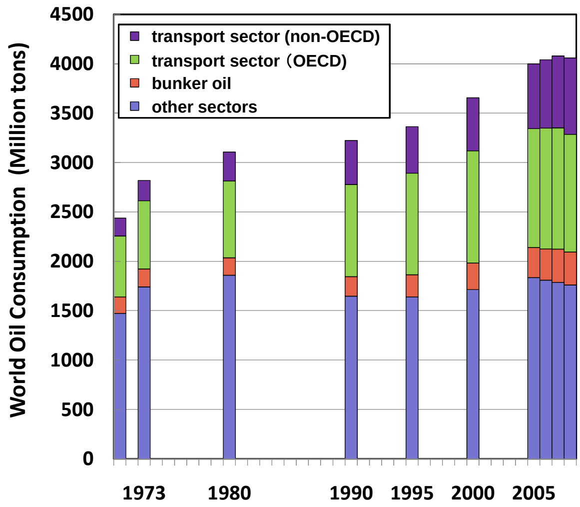

Fig.2 Proportion of the transport sector accounted for world oil consumption. (data source: EDMC[2])

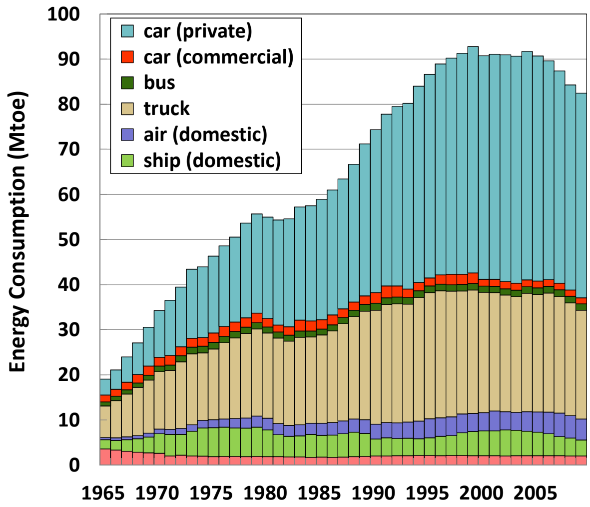

Fig.3 Energy consumption structure of Japanese transport sector. (data source: EDMC[2])

Table 1 World carbon fiber potential demand by application.

	unit		passenger automobile	truck	wind turbine blade	commercial airplane (L)
world stock	10^3		700,000@2010 1,000,000@2030 1,300,000@2050	260,000@2010 380,000@2030 500,000@2050	120@2010 1,000@2030 1,500@2050	15@2010 30@2030 45@2050
world annual production	10^3		53,000@2010 75,000@2030 100,000@2050	20,000@2010 30,000@2030 40,000@2050	25@2010 50@2030 60@2050	0.6@2010 1.2@2030 1.8@2050
CF demand per product	ton		0.1	0.4	4	25
world annual CF demand	10^3 tons per year		5,300@2010 7,500@2030 10,000@2050	8,000@2010 12,000@2030 16,000@2050	100@2010 200@2030 240@2050	15@2010 30@2030 45@2050
production volume per plant	per year		200,000	50,000	5,000	300
	per day		800	200	20	1.2
	per hour		50	13	1.25	0.075
number of plants (Assuming an ideal production plant)			265@2010 375@2030 500@2050	400@2010 600@2030 800@2050	5@2010 10@2030 12@2050	2@2010 4@2030 6@2050
CF demand per plant	10^3 tons per year		20	20	20	7.5

On the other hand, the increase in electrical energy demand due to electrification of transport sector will increase the conversion loss shown in Fig.1. However, electrical energy consumed by passenger automobile can be generated by PV (photovoltaic) with area of its own parking space. Therefore, such electrical energy demand in transport sector will increase the demand for on-site power generation such as wind turbine and PV although the challenges of the cost reduction and the storage of unstable electricity still remain.

Table 1 shows the estimated result of the world future potential demand of CF (carbon fiber). In the cases of aircraft and wind turbine blade, the annual CF demand are the same or possible expansion levels of current CF production capacity, but potential CF demand for automobiles is two digits larger than these levels. As a countermeasure, Japanese METI (Ministry of Economy, Trade and Industry) has started a national project for creating innovative CF to make its productivity ten times since 2011 fiscal year. Therefore, manufacturing cost of CF can also be expected to become drastically lower than now. On the other hand, in terms of production cycle time, mass production passenger automobile requires one digit faster than the fastest RTM's. And when the production scale will become this level, both cost reduction to steel parts level and performance improvement of recycled parts to original parts level will also be required. This paper will introduce another Japanese national project which has started to solve this production cycle time and the related issues.

Japanese National Project to Develop CFRTP for Mass Production Automobile

Concept for Total Cost Reduction In order to be adopted in mass production automobiles, we selected mainly PP (polypropylene) and partially PA (polyamide). The reason is to pursue high-speed moldability, cost reduction and high recyclability. In conventional CFRTS (carbon fiber reinforced thermosetting resin), half of the total cost is material cost and the other half is manufacturing cost. Therefore, by developing automated high cycle molding technology, the part of manufacturing cost can be reduced drastically.

In addition, the material cost of CFRTS is expensive mainly because of the inefficient CFRTS's prepreg system and the poor yield ratio (i.e., ineffective utilization rate of CF) in CFRTS manufacturing. Thus, in the case of thermoplastic, material cost is also drastically reduced, since in-plant recycling is easy and dry preform does not need the storage in refrigerator, film for removal and so on. From these results, the last target in CFRP cost reduction will be the CF cost, and which is expected to be resolved by another Japanese national project to create innovatively productive CF mentioned above.

Trade-off between Production Cycle Time and Weight Reduction Ratio If we can fully use the manufacturing time and the anisotropy of CFRP, sixty percent reduction of automotive gross weight can be expected as shown in Fig.4. However our national project aims to realize the same production cycle time as current steel-base automotive mass production, thus our manufacturing method of CFRP automotive body is similar to that of steel-base mass production method. That is, small parts are press molded in one minute and these parts are assembled by spot welding in a few seconds, but the resulting gross weight reduction rate is estimated as only thirty percent. Optimal design for more lightweight mass production automobile by using developing CFRTP is the next step.

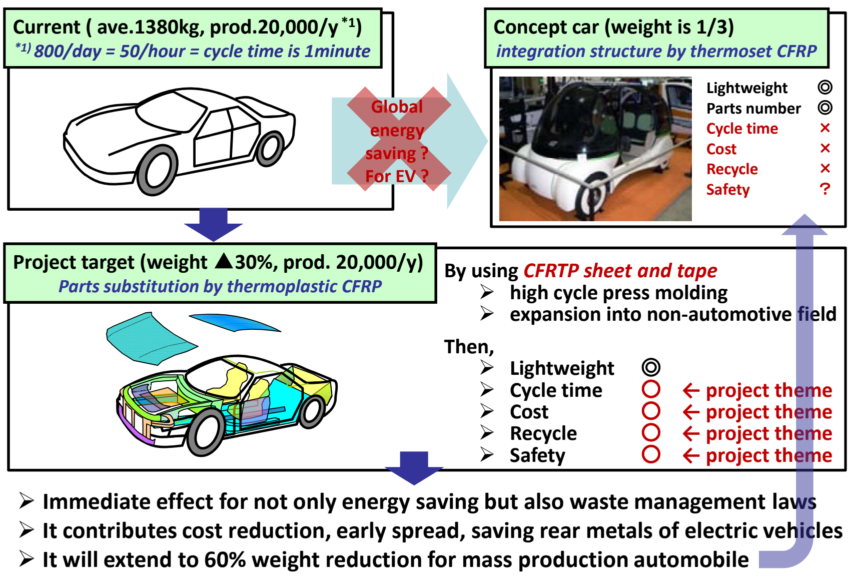

Fig.4 Concept of weight-lightening for mass production automobile.

Organization and Developing Technologies in the Project This project was established based on "Carbon Fiber Strategy" by the METI in 2007, and following technologies have been under development between 2008 and 2012 fiscal year under the total budget of four billion Japanese yen.

1. CF/PP and CF/PA sheets
   - surface treated CF and modified thermoplastics
   - continuous and discontinuous CF reinforced sheets
2. High cycle molding
   - press molding
   - bladder molding
3. Jointing
   - between CFRTP
   - between metal and CFRTP
4. Repair and recycling

Under the management of NEDO (New Energy and Industrial Technology Development Organization), the University of Tokyo has been responsible for research governing, and four companies, Toray Industries, Inc., Mitsubishi Rayon Co., Ltd., Toyobo Co., Ltd. and Takagi Seiko Co., have conducted research and development. Toyota Motor Corporation, NISSAN MOTOR CO., LTD. and Honda Motor Co., Ltd. have participated as adviser. Additionally, Yamagata University, Tohoku University, University of Toyama, Shizuoka University and Kyoto Institute of Technology have participated to develop respective themes.

Developing Preforms and High Cycle Molding Since adhesion between PP and CF is poor, both CF and PP were modified first to obtain CF/PP of high mechanical properties as shown in Fig.5. Then the next challenge was the impregnation of PP into CFs. This project has been developing two types of CFRTP preforms for high cycle molding. One is discontinuous CF reinforced isotropic sheet (Fig.6) for panel and complex shape parts, the other is continuous CF reinforced sheet (Fig.7) for primary structural parts such as frame.

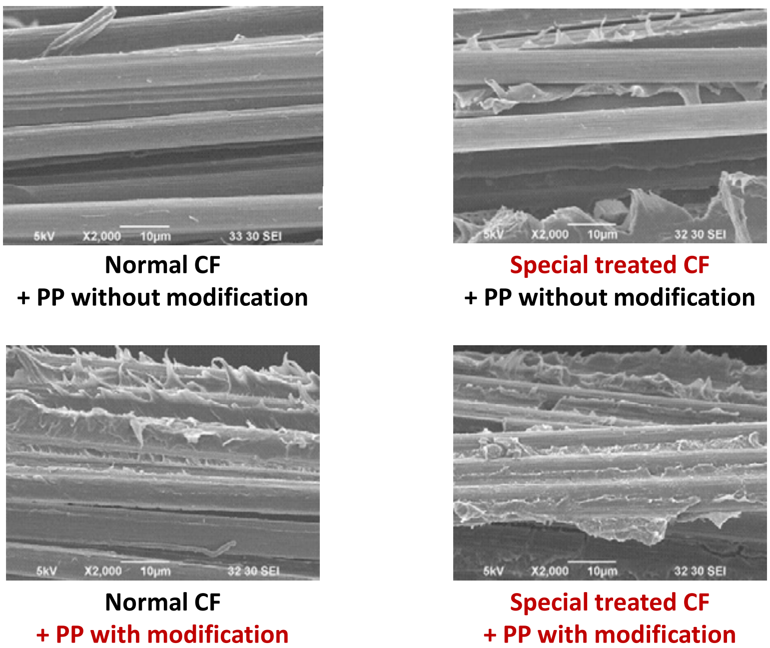

Fig.5 Effect of modification in both CF and PP to improve their interfacial adhesion.

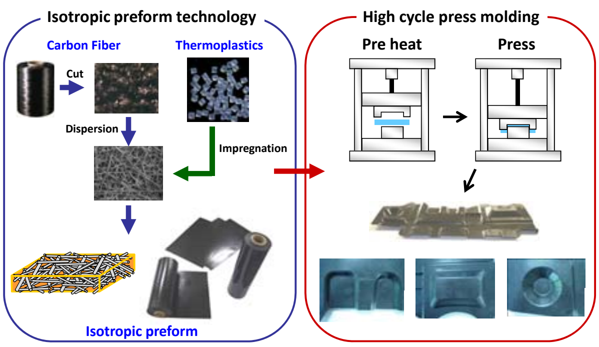

Fig.6 Discontinuous CF reinforced isotropic sheet.

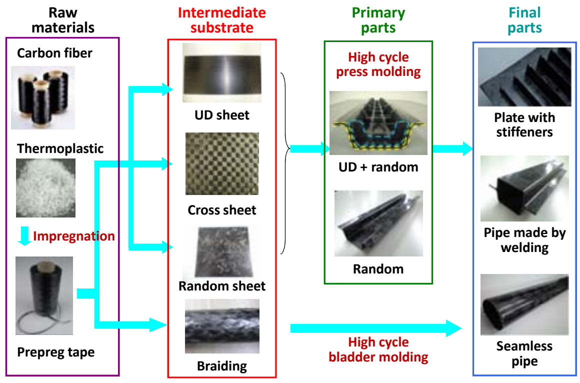

Fig.7 Continuous CF reinforced UD-tape and its various applications.

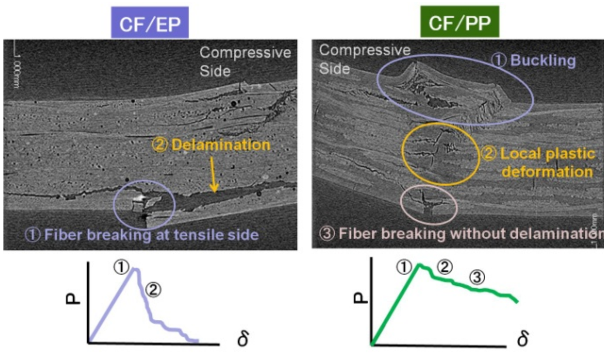

Fig.8 Difference in fracture mechanism between CFRTS and CFRTP.

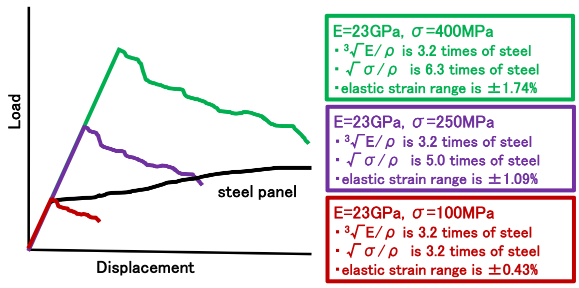

Fig.9 Comparison of CFRTPs with various strength levels.

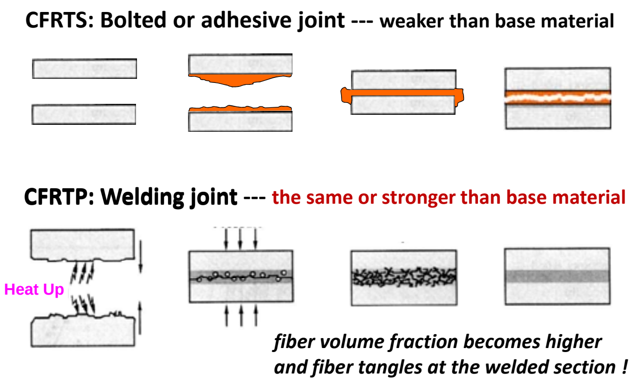

Fig.10 Difference in adhesion between CFRTS and CFRTP.

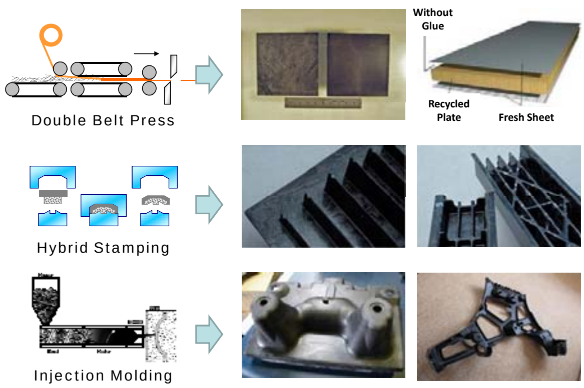

Fig.11 Three types of recycling methods developing for CFRTP.

Characteristic of Developing CFRTP The most notable feature of developing CFRTP is its fracture process without large delamination. Because of the ductile fracture process as shown in Fig.8, energy absorption capacity of developing CFRTP is almost the same level of steel. If the fracture resistance is sufficient as shown in Fig.9, strength of CFRP is not so severe criterion in case of automobile. Therefore, CF produced from various precursors (not only PAN) can be used in automobiles.

Interesting feature of developing CFRTP appears also in jointing. That is, strength of welded section becomes higher than that of base material. It may be because the CF volume fraction of welded section becomes higher than that of base material, and then fiber tangles at welded section as shown in Fig.10. The mechanism of repairing is similar to that of welding joint. During the repairing process, the local plastic deformation zone shown in Fig.8 is melted by heating, and consequently fiber reinforcement mechanism is likely to recover.

Finally, concerning recycling in the era of mass production, considering the mass balance of constitutive materials of automobile and the variations in performance of market waste, the hybrid recycling shown in the upper figure of Fig.11 may be the most promising technique because the recycled parts by this method shows the same performances as those of virgin materials.

Conclusions

Delamination has been the root of all evil for CFRTS. It is well known to cause the drastic reduction of compressive strength, accordingly the design strength is restricted and careful NDT is necessary in operating. Furthermore, we hesitate to make a hole for fastening to avoid stress concentration and delamination, therefore manufacturing facilities for near net shape molding become large and expensive.

However, developing CFRTP in this project is, in contrast, insensitive to stress concentration, and the delamination does not occur in its fracture process. The tough nature of this material not only brings large energy absorption capacity but also provides more flexible manufacturing methods of composite structure than before. The goals of this project concerning production cycle time and mechanical properties will be achieved by further improvement of developing technologies. In addition, if the constraint of the cycle time can be released, these new properties of developing CFRTP will be able to give new possibilities of both designs and manufacturing methods to composite structure.

Consequently, in the next stage, we would like to challenge to create a new composite structural design to satisfy any demanded combination of structural properties and manufacturing cycle time. For example, we will pursue the fastest cycle time to manufacture CFRTP automotive body whose gross weight reduction ratio is sixty percent of current passenger automobile. Furthermore, the social role of automobile and its new functions have been discussed recently, such as pedestrian safety, support tool for elder, etc. We believe that the developing CFRTP will contribute to realize and create such kinds of new concepts and functions of future automobile.

Acknowledgments

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