The CFRP automobile body project in Japan

Ph.D. Akihiko Kitano
Toray Industries, Inc. Ehime Plant.
General Manager of Composite Materials Research Laboratories

Eisuke Wadahara
Toray Industries, Inc. Ehime Plant.
Senior Research Engineer of Composite Materials Research Laboratories

Ichiro Taketa
Toray Industries, Inc. Ehime Plant.
Research Engineer of Composite Materials Research Laboratories

ABSTRACT

"R&D of Carbon Fiber-Reinforced Composite Materials to Reduce Automobile Weight" that is the 5-year project of NEDO (New Energy and Industrial Technology Development Organization), has been engaged since Oct. 2003. In this project, mass production and design technologies of CFRP automobile body made with continuous fiber fabric has been developed. This paper shows frame works of this project and some results.

INTRODUCTION

A strong demand for improving a fuel consumption of automobiles, which eventually contributes to reduce CO_2 emission and to prevent global warming, is existed. In Europe, about 25% improvement of the fuel consumption until 2008 was set to goal. Also in Japan, various approaches for improving the fuel consumption have been worked on actively.

One of the approaches is to reduce a weight of automobiles body. So far, automobile materials have been replaced from steel to aluminum. Moreover, plastics with and without reinforcement are being considered as possible automobile materials among automobile manufacturers. In April 2002, at Council for Science and Technology Policy, METI (Ministry of Economy, Trade and Industry) suggested the development of innovative materials, which is light and excellent in strength, to realize energy conservative and safer next generation automobile, as the priority subject for an enhancement of international competitiveness. According to aluminum, a project of aluminum alloy technologies development for automobile lightweight has already been adopted as a government program in 2004 fiscal year.

On the other hand, CFRP (Carbon Fiber Reinforced Plastics), whose strength is higher than high tensile steel, are currently in a center of attention as the most lightweight effective materials. However it has been said to be difficult to produce automobile parts made of CFRP in a mass production rate, which has been expected to be solved as soon as possible.

In Europe, TECABS (Technologies for Carbon fiber reinforced modular Automotive Structures) had been early started since April 2000 (ended in August 2004) to reduce a weight of automobiles with use of low cost CFRP and improve energy consumption and CO_2 emission drastically. Automakers such as Volkswagen, Volvo, Renault, material makers, parts manufacturers, software venders, and research institutes (Belgium, France, Germany, Switzerland and Sweden) took parts in that project. Objectives in that project are to reduce a weight of BIW (Body-In-White) and a number of parts. In 2004, trial CFRP floor pan was produced using RTM (Resin Transfer Molding) method [1].

In such situation, a material, parts manufacturer (Toray) and an automaker (Nissan) are directly cooperated and started "R&D of Carbon Fiber-Reinforced Composite Materials to Reduce Automobile Weight" in Japan. This project is a 5-year government program (NEDO) and has been engaged since October 2003.

GOALS OF THIS PROJECT

Objectives of this CFRP automobile body project is to design an automotive body which exhibits 50% lighter and 1.5 times higher impact energy absorption capability in the full wrap collision test compared with a current steel body as shown in Table 1. Especially, structural parts take over 70% in weight of BIW and take a major role in impact energy absorption. So structural parts are mainly focused on in this project. To achieve these high targets, continuous fiber fabric reinforced thermosetting resin is selected as the material of automotive body. Conventionally, it was assumed that continuous fiber fabric has a difficulty in handling and is inappropriate for mass production, although it is excellent in strength and stiffness. So 10-minute molding, which is appropriate for automobile parts production rate, 30,000 unit/year, has been also set to the objectives of this project. There are many CFRP molding methods as shown in Figure 1. For example, Injection molding or SMC are appropriate for high rate production, but those discontinuous fiber and cannot be expected to be high mechanical properties. In opposite side, prepreg and RTM use continuous fiber and can be expected to be high mechanical properties, but they are inappropriate for high rate production. Especially, RTM use dry fabric (no resin impregnated fabric) that is superior to prepreg in drapability and easy to fit deep draw shape as automobile parts are often so. Innovative technology, “Short cycle RTM” has been newly developed in this project to make full use of that RTM characteristics and realize 10-minute molding cycle.

Figure 2 shows the schedule. As a preliminary of this project, Toray and Nissan had made some studies to confirm concepts. NEDO recognized the results of these researches and formally signed on for this project in October 2003. In addition to Toray and Nissan, 5 universities, that is to say, Tokyo Institute of Technology, Nihon University, Kyoto Institute of Technology, University of Hyogo and University of Tokyo has been taken part in. As the milestones, 10-minute molding demonstration applied to door panel was set until March 2006. Also, 10-minute molding demonstration applied to platform and design of 50% lighter and 1.5 times safer CFRP BIW with compared with steel one was set until March 2008.

Table.1 Objectives of this project.

	Target	Steel
Lightweight (Vehicle mass)	0.5 (200kg)	1.0 (400kg)
Safety (Energy absorption)	1.5	1.0

*BIW of 1.5t vehicle

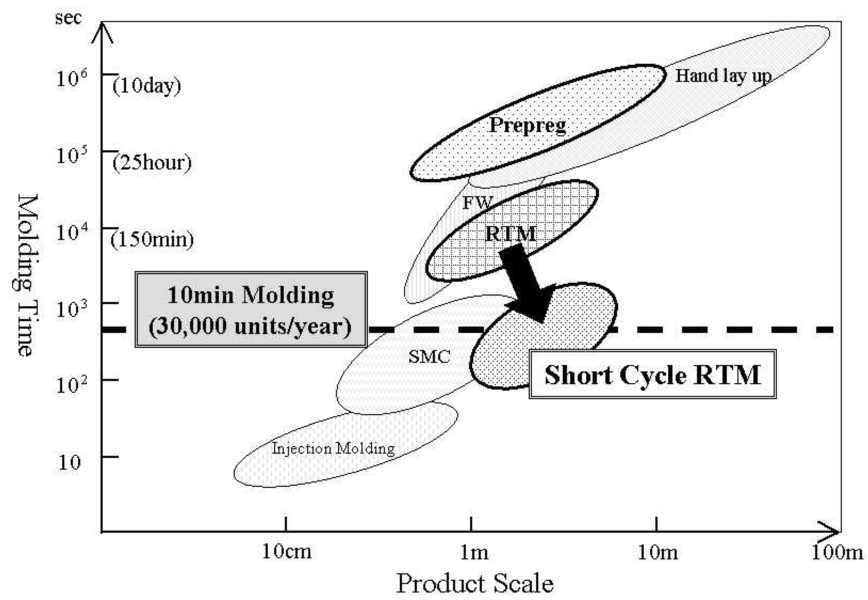


Figure 1 Various molding method and objectives of this project.

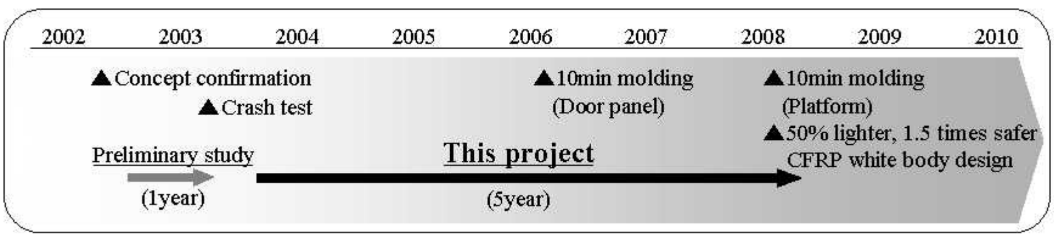


Figure 2 Schedule and milestones of this project.

OVERVIEW OF RESULTS OF TECHNICAL SUBJECTS

In this project, there are 4 technical subjects that are corresponded to the each stages of automobile life cycle as shown in Figure 3.

First one is “Short cycle integrated fabrication technology” this subject is corresponded to “Fabrication” stage in the automobile life cycle. A technology that realizes a short cycle fabrication of CFRP automotive body made of continuous fiber fabric reinforced composites is developed in this project.

Second one is “Metal/CFRP joint technology”, this subject is corresponded to “Assemblage” stage. A technology of adhesive joint between metal and CFRP having almost equivalent strength to conventional welding joint between metals is developed.

Third one is “Safety design technology”, that is corresponded to “Use” stage. A simulation technology for CFRP energy absorber is developed and that technology assists CAE design for automotive body. In addition, a CFRP automotive body, that is 1.5 times larger in energy absorption than steel body, is designed.

Last one is “Recycle technology”, that is corresponded to “Scrap” stage. Dismantlable adhesive is developed to separate easily metal and CFRP in scrapping. In addition, to apply recycled CFRP to automobile non-structural parts, a technology for re-fabricating CFRP materials which can be recycled for additional two times, is developed.

The current statuses of above-mentioned four subjects are summarized below and also future works to realize CFRP automobiles are addressed.

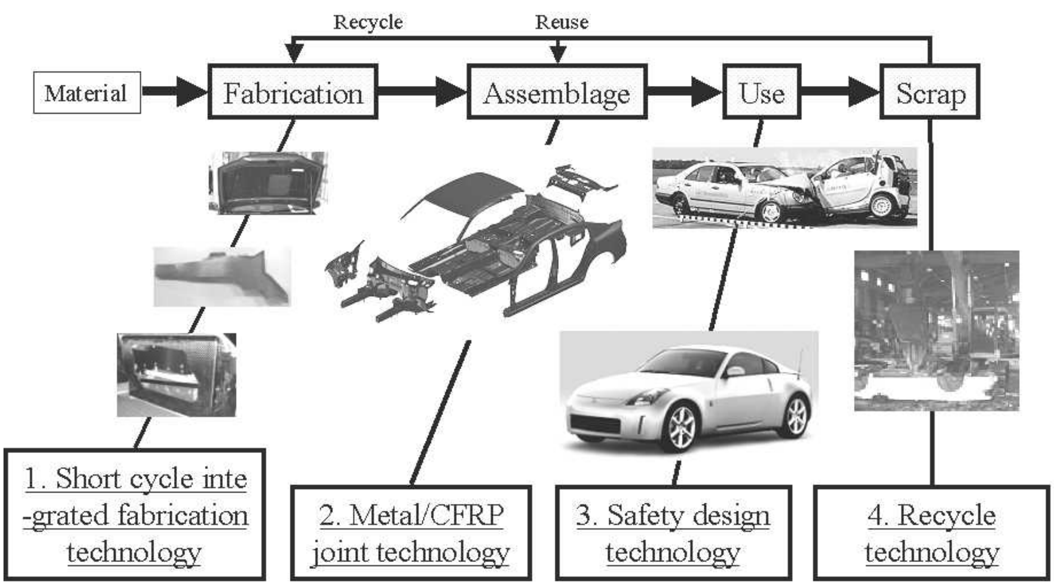


Figure 3. Four technical subjects in this project.

Subject 1: Short cycle integrated fabrication technology

The goal of this project is to develop of an automobile primary structure parts, platform can be fabricated for 30,000 unit/year. Fabrication quantity is decided by the time from the molding tool open to molding tool close, what is called molding cycle time because molding tool is generally very expensive. If 1 molding tool is used for production, it is necessary to realize 10-minute molding. RTM method is well-suited to automobile parts that are often in complicated shape, short cycle RTM has been developed as shown in Figure 1. Also preforming process, which continuous fiber fabric is made to 3D preform, should be developed for shortening the process time to go hand-in-hand with short cycle RTM [2].

In this paper, two innovative technologies to realize short cycle RTM are introduced below. So-called, “Rapid cure resin” and “Rapid impregnation method” have been developed in this project. As shown in Figure 4, conventional RTM had taken a long time to achieve both appearance quality and mechanical property. For example, it had taken 160 minutes to mold $2m^2$ panel parts with use of epoxy resin. 20% is the resin injection time to impregnate resin into dry fabric and more than 50% is the resin cure time. These two steps took the large part of molding cycle time that should be shortened drastically. The goals are 3 minutes resin injection and 5minutes resin cure. That means the total time from resin injection to demolding is shortened 1/15, from 125 minutes to 8minutes.

At first, “Rapid cure resin” has been developed. RTM is the molding method that resin impregnates into dry fabric. Thus, resin flow time in low viscosity less than 300 cps to resin flow through the dry fabric easily need to be long. Conventional RTM resin used to be amine cure epoxy resin because of high mechanical property. To achieve the long resin flow time, resin cure time also becomes long as shown in Figure 5. Breakthrough is an anionic polymerization with a chain transfer agent. This cure mechanism enables 3 minutes low viscosity to flow through dry fabric easily and only following 2 minutes cure rapidly at same temperature. The mechanical properties are almost equivalent to that of the conventional RTM resin and its composites, which indicates the rapid cure resin composites are appropriate for automobile structural parts [3].

Secondly, to utilize rapid cure resin fully, resin injection time should be shortened less than 3 minutes. As shown in Figure 6, Conventional RTM injection method that resin flows in face took long time because of fluid resistance of dry fabric, and so larger scale of molded product took more time. Sometime resin flows along the edge part of fabric where fluid resistance is very low. Thus, impregnation could not be controlled and non-impregnation part could be often generated. That is one of the reason RTM lacks in consistency. In addition, because in this project 3 minutes impregnation should be applied to large-scale parts such as platform, completely different method had been required. Breakthrough is multi gate injection. According to developed rapid impregnation method, impregnation has been controlled though the fabric thickness at a stretch and resin has not through the edge of fabric in early stage. Finally this method achieved 2.5 minutes impregnation. Multi gate injection method seems to be worried about weld. Generally, decline of mechanical properties at the region of weld is serious on injection molding with thermoplastic, but in this case, thermosetting resin is applied and the resin from different gate meets with having reactivity, weld does not occur.

These two innovative technologies have successfully allowed the 10 minutes molding demonstration applied to door inner panel in February 2006. Figure 7 shows the door inner panel fabricated by these technologies.

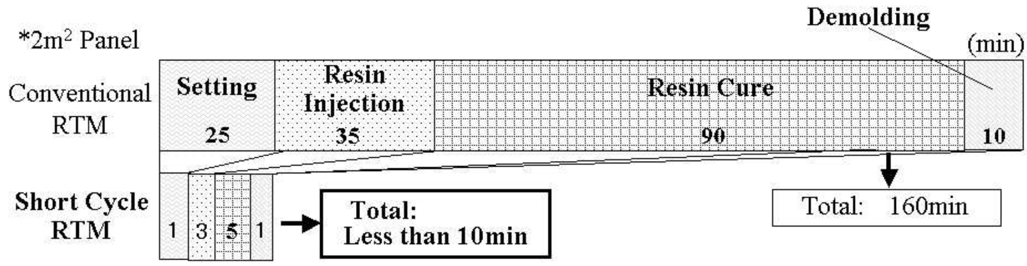


Figure 4. Time apportion of molding process.

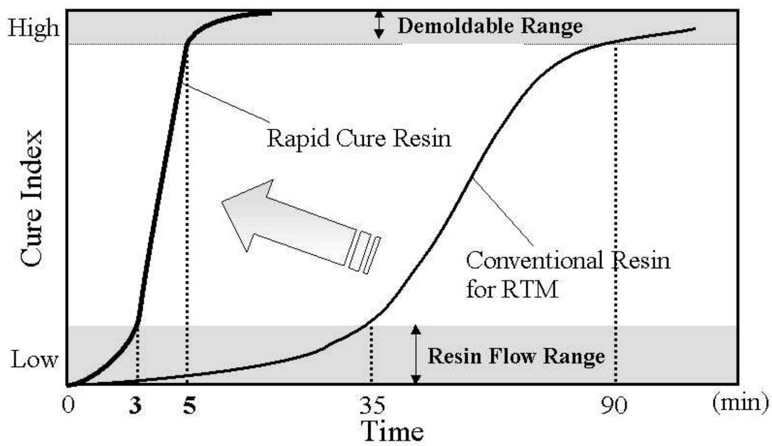


Figure 5. Concept of cure index curve of rapid cure resin.

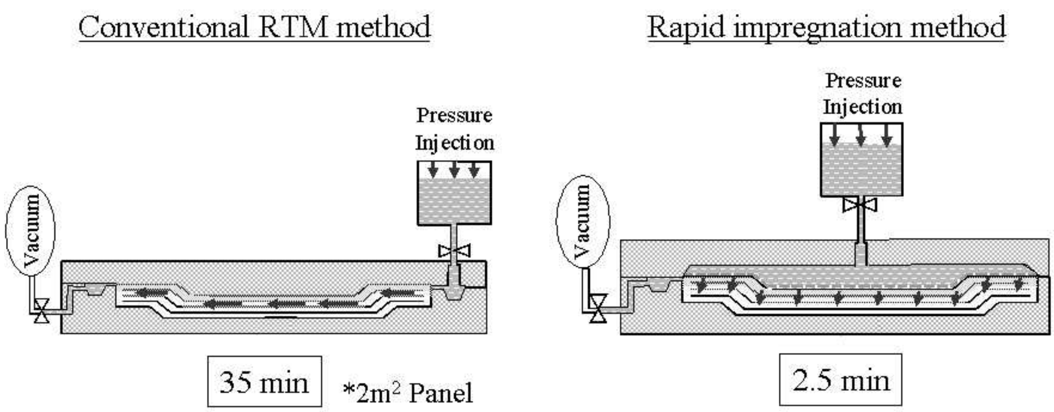


Figure 6. Schematic of injection methods.

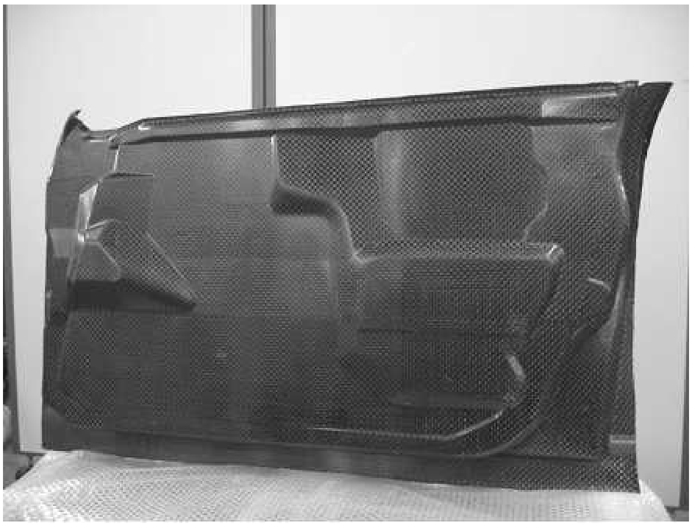


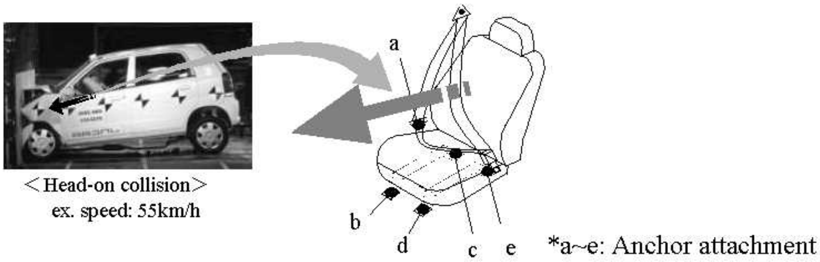
Figure 7. Door inner panel demonstrated 10-minute molding.

Subject 2: Metal/CFRP joint technology

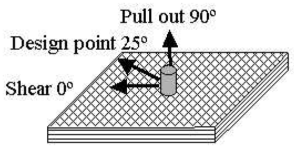
Joint technology is the key of BIW assemblage. In this project BIW are planed to be fully made of CFRP, but especially at joint parts there are many metal inserts and different materials meet. The combination of co-cure bonding [4], adhesive bonding and mechanical joints need to be applied properly. On the one hand structural adhesive database has been completed and on another hand various attachment parts have been concretely developed one by one.

Structural adhesive database takes account of adherend types (steel, aluminum, CFRP) and has been taken under static, durability, fatigues and exposure condition. The adhesives of which bond strength is more than 20MPa under automobile environment, through out from –40°C to 80°C are screened out.

Also various attachment parts, especially which are often critical under automobile use, are selected and concretely verified one by one because input loads and required performances of any attachments are unique to each other. For example, sheet anchor and sheet belt anchor attachments have been developed as shown in Figure 8. These attachments are very important for passenger safety in crash and also required specs are severe. The attachment specification and shapes are analyzed by FEM and designed. Actually in mechanical test, these attachments are superior to present attachment in various direction loads.



Mechanical test for anchor attachment



Load direction	Failure load [kN]		
	Goal	CFRP	Steel (present)
Vertical (pull out)	21	37	21
Horizontal (shear)	19	19	19
25° direction (a)	12	14	12

*specimen weight is same

CFRP specimen

Figure 8. Example of anchor attachment mechanical test.

Subject 3: Safety design technology

The prime objective is CFRP BIW design. Preliminary design of that was finished in March 2006. To realize aggressive target, 50% lightweight and 1.5 times more energy absorption compared with steel body, accurate simulation technologies and energy absorption structure technologies have been developed.

As accurate simulation technologies, CFRP dynamic analysis is very important because passenger safety in crash is taken quite seriously in automobile design. CFRP dynamic analysis in large scale such as full automobile body are insufficient knowledge, and new types of CFRP parts such as crush tube are very difficult to stable analysis though the crush tube takes important role in crash and needs to be accurate analysis.

Also as energy absorption structure technologies, energy absorbers in various fracture modes are developed. The energy absorber, CFRP crush tube was permanently attached to actual CFRP parts, front side member and proved its potentiality in head-on collision test as shown in Figure 9. The CFRP crush tube gained more energy absorption than the target, present steel one.

Joint of front side member

Head-on collision test

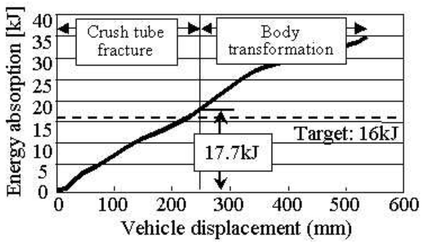


Figure 9. Verification of energy absorption in crash test.

Subject 4: Recycle technology

Cost and recycle matters had been always supposed to be weak point of CFRP automobile use. two technologies in this project can be defied that common wisdom. Recycle starts at the step of the separation between metal attachment and CFRP scraps of automobile body. In the next step, standard recycled CFRP material is fabricated with use of CFRP scraps. That standard recycled CFRP material can be use in press and injection to make automobile non-structural parts. In these two steps, separation and fabrication, new technologies have been developed.

In separation steps, an innovative technology, dismantlable adhesive has been developed. The separation concept is as follows. Dismantlable adhesive includes the fillers that expand in high temperature. While the adhesive is heated, its matrix modulus and strength is getting down and its fillers expanding force is going up. The adhesive can be designed to separate matrix and fillers at certain temperature. This concept achieves metal attachment and CFRP scraps separation in few minutes easily. Of course, as a structural adhesive, its bonding strength should be more than 20MPa. Both heat-resistance at 80°C and dismantlability more than 150°C not to dismantle in coating process are also required. By applying expandable graphite to the filler, the dismantlable adhesive that mature these specs are developed and less than 5 minutes dismantlability has been demonstrated as shown in Figure 10.

In fabrication steps, recycled CFRP material can be endured Three times as automobile parts. CFRP scraps are collected and crushed. That crushed CFRP and thermoplastic resin are compound at properly content ratio and pelletized to make recycled CFRP material for standard use of injection or press. As shown in Figure 11, carbon fiber are homogenously distributed in the material and that's mechanical properties are enough to be applied to automobile non-structural parts. Also required mechanical properties can be improved and controlled by crushed CFRP content ratio.

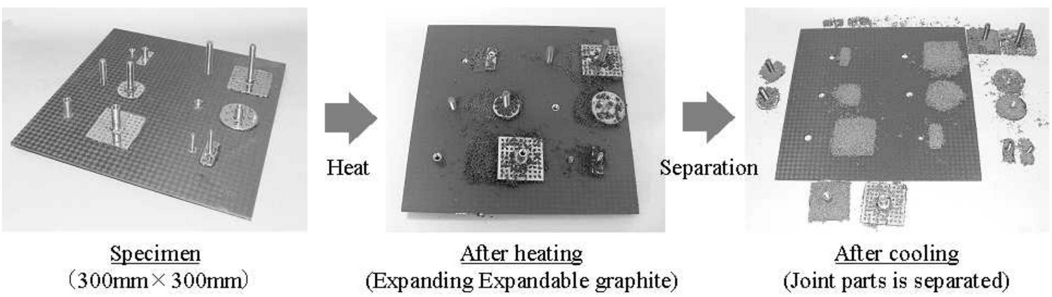


Figure 10. Demonstration of dismantlable adhesive.

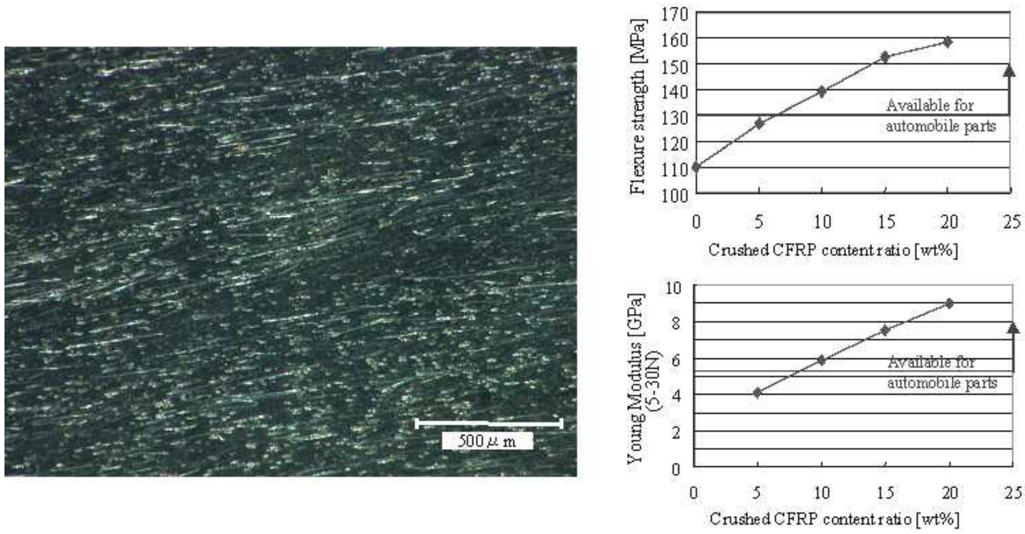


Figure 11. Example of recycled CFRP examination.

RESULTS SUMMARY AND FUTURE WORKS

Two innovative technologies, “Rapid cure resin” and “Rapid impregnation method” have been developed. Rapid cure resin achieved 3 minutes resin flow and total 5 minutes resin cure at same temperature. Rapid impregnation method achieved 2.5 minutes impregnation into dry fabric. These technologies have enabled short cycle RTM, only 10-minute molding and demonstration succeeded with applied to door inner panel in February 2006. Scale-up study of 10-minute molding is now going on and will demonstration with applied to platform until March 2008. Also automation system of preform process with use of continuous fiber fabric is currently under development.

Screening of adhesives of which bond strength is more than 20MPa through out from –40°C to 80°C and joint technologies suitable for automobile body structure have been almost developed. Now automation of bonding process design is carried forward.

Preliminary design of BIW was finished. Head-on collision test with CFRP front body is planed in 2006 and its results will be returned on next design of BIW.

An innovative adhesive that can dismantle adherends has been newly developed and 5 minutes dismantlability was demonstrated. Also recycled CFRP materials have been examined for applying to automobile non-structural parts and realize closed recycle. This recycled CFRP materials will be demonstrated to endure three times use as automobile parts.

ACKNOWLEDGEMENTS

This R&D has been conducted as the part of “New Global Warming Prevention Technology Program” supported by NEDO. The authors would like to thank Nissan Motor Co., Ltd., universities partners for their technical contributions.

REFERENCES

1. I. Verpoest, T. C. Thanh, and S. Lomov. 2005. "The TECABS project: development of manufacturing, simulation and design technologies for a carbon fibre composite car," The 9th Japan International SAMPE symposium, pp. 56-61.

2. I. Taketa, A. Kitano, and M. Yamasaki. 2005. "Short cycle production process of automotive body," The 9th Japan International SAMPE symposium, pp. 68-73.

3. T. Kamae, G. Tanaka and H. Oosedo. 2005. "A rapid cure epoxy resin system for a RTM process," The 2nd JSME/ASME international Conference of Materials and Processing 2005, PMC-12.

4. M. Yamasaki, A. Kitano, and I. Taketa. 2005. "Co-cure bonding method for structural parts of automobile," The 9th Japan International SAMPE symposium, pp. 74-79.