# A DRY ALIGNING METHOD OF RECYCLED DISCONTINUOUS FIBERS FOR HIGH PERFORMANCE CFRTP

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**Abstract**
A dry fiber alignment method is newly developed for long reclaimed carbon fiber by utilizing modified yarn manufacturing process. In this method synthetic fibers are used as suspension of discontinuous carbon fiber in order to be processed in dry. Both fibers are aligned and comingled homogeneously into sliver by multiple times drafting and combing, and then the sliver is spun into yarn. In this work sliver was made successfully from cut carbon fiber of 200mm long. By setting the yarn in one direction and hot-pressing, aligned discontinuous fiber reinforced composites were produced. It was observed that almost all the fibers were well dispersed and aligned perpendicular to cross section of the composite. Tensile modulus and strength of the aligned composite specimens were compared with those of specimens made of the same yarn with randomly setting. The fiber orientation was evaluated by using micro X-ray CT images. Fiber alignment level and mechanical properties achieved by the developed method are presented.

## 1. Introduction

Accompanied with the growth in composite material use recycling has been considered to be a crucial requirement. In order to utilize recycled carbon fibers as reinforcement for high performance structural composites, such conditions as long fiber length, high alignment and high volume fraction of fiber must be satisfied. For alignment of discontinuous fibers some dry and wet process, e.g. modified papermaking technique has been developed [1-4]. They used a liquid medium as suspension of discontinuous fibers and flow-induced momentum to align fiber. Successful results were achieved for fibers of shorter than 5 mm long. On the other hand longer fiber for efficient stress transfer is preferable to achieve higher mechanical performance. But in case of long fiber the spacing between the fibers is not enough for fibers to rotate their direction and fibers are easy to interact. From such reasons alignment method using hydrodynamic effects is harder to apply for long fibers [4]. Moreover hydrodynamic alignment methods need to improve low productivity and dealing of large amount of a liquid medium.

Therefore the aim of this study is to develop a dry alignment method for long fiber. In order to make the process in dry fluffy synthetic fiber was employed as a medium to suspend discontinuous fibers instead of a liquid medium. And mechanical interaction between discontinuous carbon fiber and fluffy synthetic fiber was used to align, because synthetic fibers can be aligned by mechanical effects into sliver due to their nature easy to slide and crimp. Carbon fiber can be aligned together with synthetic fiber if some interaction makes discontinuous carbon fiber follow the synthetic fiber. In order to cause such mechanical effect we used a textile machine called “Gill” which was used for shaggy and rigid wool to be aligned. Mixture of discontinuous carbon fiber and synthetic fiber were drawn between rollers of a little different rotation speeds and stretched in one direction. During drawing synthetic fibers are easily aligned and accompanied carbon fibers may follow the synthetic fiber action with

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assist of combing. To make the developed method capable to apply to long fiber, tangled long carbon fiber was opened before it was suspended on the synthetic fiber. An usual carding machine could not work well for carbon fiber, so a modified garnet machine combined with pneumatic action was employed in this work [5].

Roughly aligned and comingled sliver is spun into yarn and in the process carbon fibers were again stretched and aligned. Once discontinuous fiber made into yarn form existing composite manufacturing technologies for continuous fibers can be easily adapted to make aligned preforms. Anisotropy in preforms is controlled in various forms via conventional textile technology.

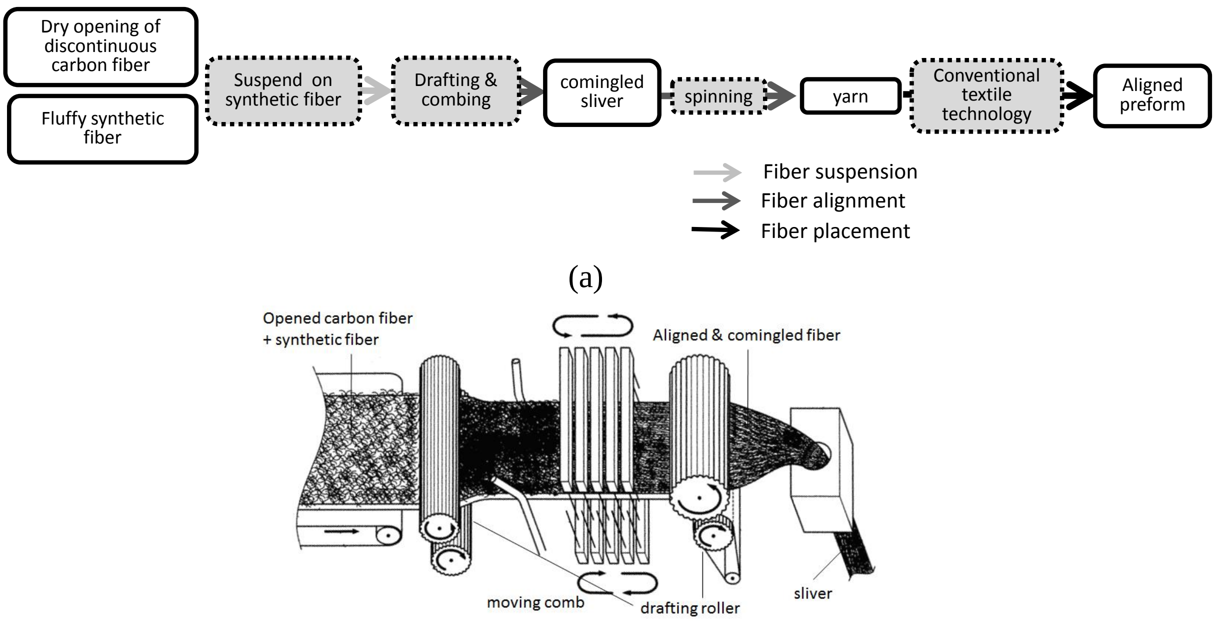
This paper introduces the developed fiber alignment method which enables handling fibers in dry. Comingled sliver was produced from discontinuous carbon fiber from 200mm long and polypropylene and then unidirectional composite sheets were made by orientating yarn spun from the sliver in one direction. Tensile stiffness and strength of the unidirectional composite specimens were examined with compare to those obtained from specimens of randomly placed yarn composite. Fiber orientation in the composite specimen was characterized using X-ray CT images and related to the tensile properties.

## 2. Experimental

### 2.1. Alignment procedure and mechanism

The procedure for forming aligned discontinuous carbon fibers preform comingled with synthetic fibers is comprised of the following steps as shown in Fig. 1(a) [6],

(a) Opening discontinuous carbon fibers.
(b) Suspending the opened carbon fibers on synthetic fibers.
(c) Drawing the fibers together in one direction using rollers of a little different rotating speed.
(d) Combing together with drawing into comingled sliver.
(e) Spinning the comingled sliver into yarn.
(f) Placing the yarn in one direction to form aligned fiber preform.




(b)

**Figure 1.** Discontinuous fiber alignment process; (a) flow chart and (b) equipment.

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In Fig. 1(b) configuration of discontinuous fiber alignment equipment is illustrated schematically.
As shown in Fig. 2, the fiber alignment mechanism is that the carbon fibers orientation is changed to the drafting direction by following synthetic fibers which suspend the carbon fibers, because synthetic fibers are easily stretched and aligned by drawing owe to their nature which is easy to crimp. With reduction in thickness during drawing carbon fibers were also comingle with synthetic fibers in a uniform manner and resulted in comingled sliver. When the sliver spun into yarn, discontinuous carbon fibers were again aligned in axial direction in the stretching sliver. Views of fabricated sliver and yarn were as shown in Fig. 3. Once discontinuous fiber is made into yarn, traditional textile methods are available for making oriented preforms.

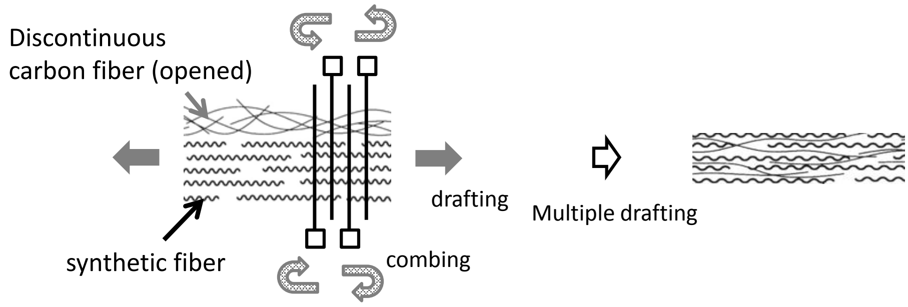


**Figure 2.** Schematic drawing of mechanism of the developed alignment method.


**Figure 3.** View of sliver and yarn manufactured by the developed method.

### 2.2. Materials and fabrication of composites

Fibers used in this experiment were PAN-type carbon fiber of high strength (T700SC-12K Toray Co.,ltd.) and polypropylene fiber (Daiwabo Polytec Co.,ltd.). The sizing agent of carbon fiber is compatible for epoxy resin. Carbon fiber was cut in 200 mm long from continuous tow to simulate reclaimed discontinuous fiber and opened by a modified carding machine. Polypropylene fiber was used as served.
Composite samples with different fiber orientations, unidirectionally and randomly oriented respectively, were prepared by hot pressing arranged yarn in a semi-closed mold. Unidirectional composites were fabricated by stretching the yarn in one direction, and random ones were fabricated by dispersing cut yarn of 80 mm long. The press-molding were performed at 200°C, under 2 MPa and for 10 min. The volume fractions of carbon fiber evaluated by a combustion method were 13.3% and 12.8%, in unidirectional and random composites respectively.

### 2.3. Fiber orientation measurement

Fiber orientations were determined by using X-ray images in order to obtain entire information over the thickness direction of composites. Composite plates were cut out in size of 10 × 10 mm for X-ray observation. Images of the parts were taken by a micro X-ray CT (SkyScan 1172 Bulker) whose

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spatial resolution is about 0.5 μm. Probability density functions for in-plane fiber orientation were obtained from the images with processed by a softwear for fiber analysis in composite material (VGStudio MAX Volume Graphics).

### 2.4. Mechanical testing

Specimens used for tensile tests were cut out form the hot pressed plate so as that direction of the aligned carbon fiber coincide with tensile direction. The dimensions of tensile specimen were 10 mm width, 100 mm length and 1 mm thickness. Aluminum end tabs were adhered for all the specimens. Tensile tests were performed by an electro-mechanical testing machine (3376 Instron) at a cross head speed of 1 mm/min. Strain was measured by a contact-type extensometer whose gage length is 50 mm (2639-111 Instron). Load was measured with a 30kN load cell (Instron).

## 3. Results and discussion

### 3.1. Fiber orientation

Fig. 4 shows a microscope image of the cross section of the unidirectionally oriented fiber composite sample. From the image carbon fibers were well aligned perpendicular to the cross section and uniformly dispersed.

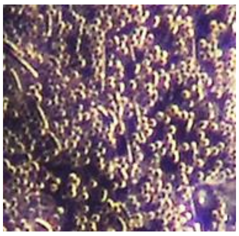
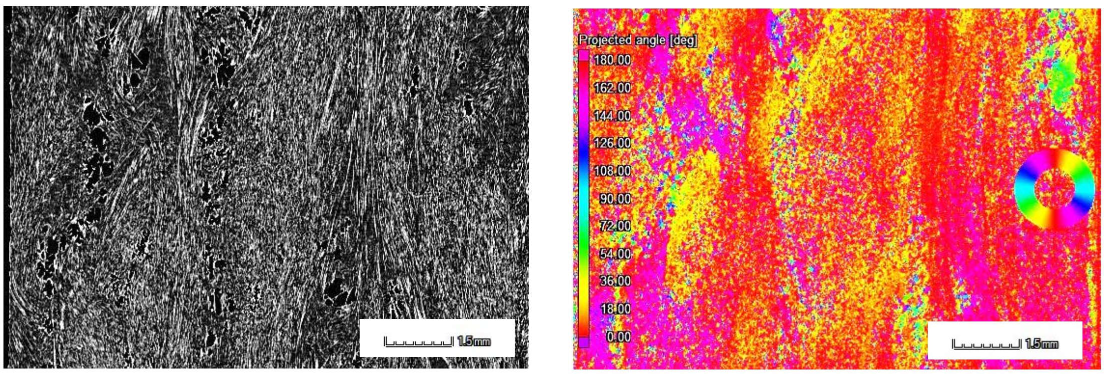


**Figure 4.** Microscopic image of cross-section of unidirectional composite sample.

Fig. 5(a) shows a X-ray image of the plane along tensile direction of the unidirectional composite sample. Owing to the high detectability of the X-ray scanner individual fibers in the composite were observed clearly.  In Fig. 5(b) the analyzed result of fiber orientation for Fig. 5(a) was shown, which was evaluated by the analyzing softwear. The evaluated direction angles are seemed to reasonably reflect the observed image.




(a) (b)

**Figure 5.** In-plane X-ray image of unidirectional composite sample and result of fiber orientation analysis.

Probability of fiber orientation angle for each 1° was shown in Fig. 6. Form Fig. 6, in case of unidirectional composite specimens about 70% fibers were in the rage of ±14° as shown in Fig. *. The reason of variety in fiber orientation was that discontinuous carbon fibers changed their orientation

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when they were spun into yarn. The most frequent fiber angle in the yarn was a little misaligned against the longitudinal axis. The fiber angle in case of random composite specimens manufactured from the same yarn in comparison showed more uniform distribution.

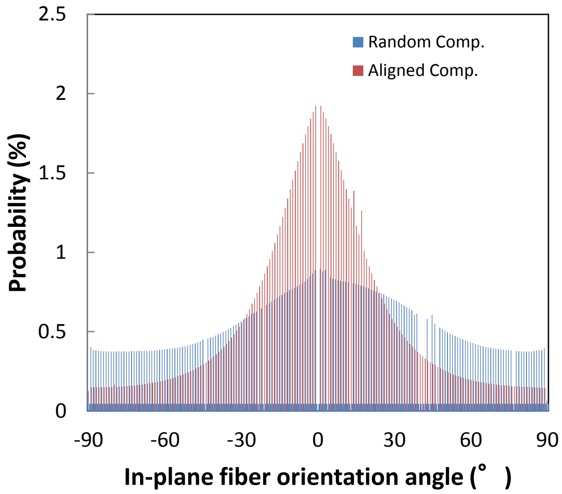


**Figure 6.** Probability for in-plane fiber orientation of composite specimens.

## 3.2. Mechanical properties

Fig. 7 shows the tensile test results of in the fiber alignment direction. The reference experimental result obtained from continuous fiber unidirectional composites specimens of the same carbon fiber and matrix resin.

The levels of tensile modulus and strength of aligned fiber composite specimens were relatively low as compared with the continuous fiber unidirectional composite specimens due to the widening of fiber orientation shown in Fig. 6. But with compared to tensile modulus and strength of the composite specimens in which fibers were randomly oriented, tensile modulus of aligned fiber composite specimens was higher than three times. Because they were manufactured from the same yarn and only different in fiber orientation, increase in tensile modulus was considered to be resulted from fiber alignment effect. Fig. 8 showed fracture surface of the aligned composite specimen and the not-aligned random composite specimen. Fiber pull-out was observed in the both fracture surface but in the fracture surfaces of the aligned composite specimen it was observed that pull-out fibers were well aligned as intended.

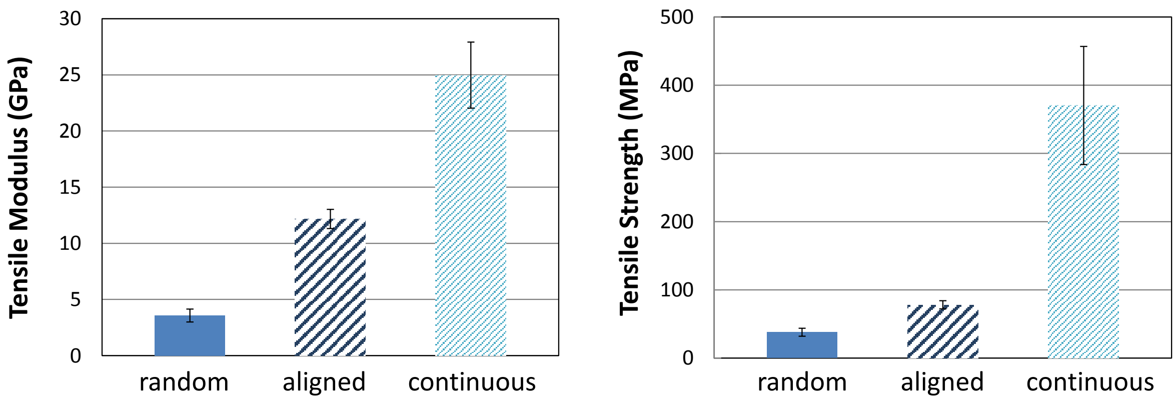


**Figure 7.** Tensile modulus and strength of composite specimens.

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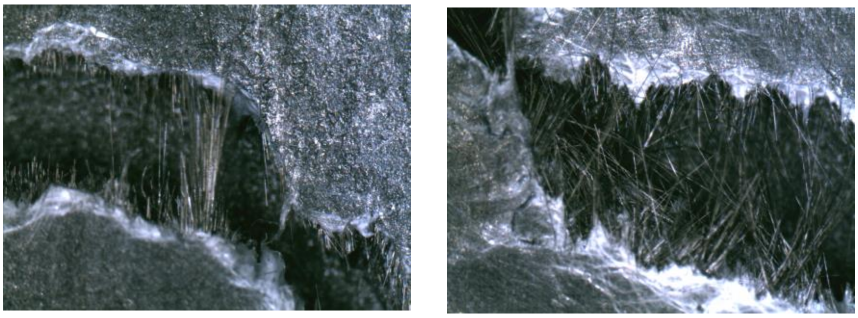


**Figure 8.** Fracture surface of aligned carbon fiber/PP composite specimen.

## 4. Conclusions

In this paper, a new discontinuous fiber alignment method using a modified textile method was introduced. This new method utilizes fluffy synthetic fibers as a suspending medium of discontinuous fibers in order to make the process in dry. And it is modified applicable for long discontinuous fibers. Aligned composites were successfully fabricated from the 200 mm long carbon fibers and PP fibers. Their tensile modulus was higher by more than three times compared to that of randomly oriented composite specimens. In the future work, this new method for alignment of discontinuous fiber is to make variety of orientation angle smaller to make tensile modulus higher.

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