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# Forming low-cost, high quality carbon tows for automotive application

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**Abstract.** Carbon fiber reinforced composites are widely used in many industries due to their high performance. Its application in the aerospace industry has increased significantly, however, in mass produced automobile sector it is still limited. The current production of carbon fiber tow is slow and capital intensive. Thus, carbon manufactures produce higher tow counts to increase production rate to reduce its cost. In order to offset the higher cost of carbon fiber composite, an innovative and unique approach has been developed. The higher tow count carbon spools are split into smaller tow counts. Due to the delicate nature of carbon fiber, it is important to control the filamentation during that process. Different splitting process line strategies have been developed in this research work for understanding the process limitations and challenges involved. The process was made feasible for production by developing a fully automated process line with a laser feedback system. The system splits a 12K spool into two 6K tows. The quality of the 6K split tows has been determined statistically by recording real time data from the laser during the splitting process. It was demonstrated that the proposed process effectively controls filamentation and produces consistent tow quality.

## 1. Introduction

The superior mechanical performance of carbon composites has significantly increased its application in the aerospace industry. However, its usage remains limited within high volume automotive sector and other clean energy applications due to its costs. Currently, the carbon precursor is almost 50% of overall cost while other 50% is conversion and surface treatment [1]. The carbon manufacturers are developing new methods to produce low-cost precursor and investigating economical production methods. However, it has not reached to the threshold where it can be mass applied.

The production of carbon fiber is slow and capital intensive. Therefore, tows with a higher count (number of filaments) are produced to reduce its cost. The 3k carbon spool is almost three times expensive than a 12k spool. There are several industrial applications where finer tows are desirable due to better drapability and mechanical performance such as discontinuous robotic preforming. The tow count has a profound influence on the performance of discontinuous fiber composites. Rondeau [2] has compared the stiffness and strength of 12k, 6k and 3k discontinuous fiber composites to unidirectional continuous prepreg counterparts. It has been observed that the finer tow count showed better stiffness and strength retention compared to the 12k and 6k composites. As the fiber bundle size decreases, it splits into smaller sub-units during the spraying process and provides the homogenous distribution of filaments on the tool surface. A robotic based preforming system, Programmable Powder Preform



Process (P4), has been developed by the automobile sector for low-cost, low waste and high production [3][4]. Initially, this process was conceived for glass fiber reinforcement, however due to the ongoing development in this process, it is now also suitable for carbon fiber reinforcement.

One of the proposed approaches to reduce the cost of low-count fiber is to possibly split higher tows into finer tows. This research is focused on developing an innovative splitting method to be applied on the P4 preforming system. There is limited research available on the carbon fiber splitting process. Peter A. Kiss et al in his patent [5] has designed a splitting process machine which splits 48K tow into 7-10 strands using various combinations of smooth grooved guide and Splitter bars having crown radii and groove depths. He documented the challenges faced such as fiber crossovers, fiber breakage, and creation of fiber fuzz. His patent design could not achieve complete success. Another research conducted on 'Low-cost carbon fiber production' attempted several techniques to split large tows[1]. However specific details of the process and production success were not made public.

In this research a unique approach has been adopted to split 12k carbon tow into two separate 6k tows. The split 6k tows were wound back onto separate spools by the rewinding machine. Tow splitting is a complex process in which the optimization of the process parameters plays an important role to facilitate the splitting process. Different designs of the splitting process line have been developed in this research work in order to understand the process limitations. This includes the use of high frequency pneumatic muscles to oscillate the splitting blade, and a static blade splitting system. A fully automated process line with a laser feedback system has been developed to achieve optimization. Finally, the quality of the split tows has been determined statistically by recording the real-time data during the splitting process.

## 2. Material and Methods

### 2.1. Material

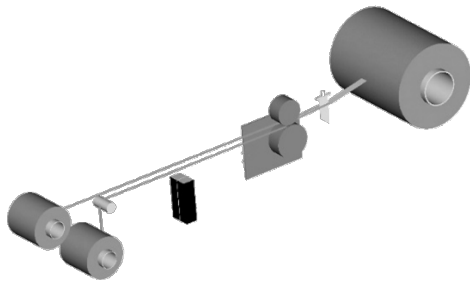
The 12K carbon fiber spools (T700sc) was procured from Toray Torayca. The spool properties are shown in Table 1.

**Table 1.** 12K carbon fiber Properties

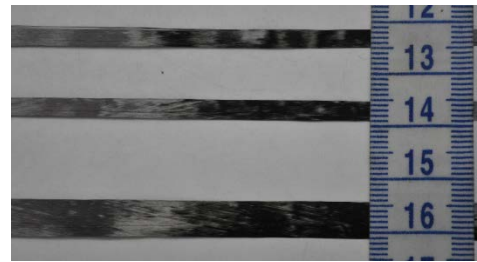
|                        | Fiber Properties       |
|------------------------|------------------------|
| Tensile Strength       | 4900 Mpa               |
| Tensile Modulus        | 230 Gpa                |
| Filament Diameter      | 7 $\mu\text{m}$        |
| Density                | 1.80 g/cm <sup>3</sup> |
| Sizing type and amount | 60E with 0.3%          |

### 2.2. Tow Splitting line Arrangement

The proposed tow splitting system consists of three main components; tangential unwinding machine, splitting station and winding machine. The splitting process diagram is shown in figure 1. The 12k carbon spool was held in the tangential unwinding machine. The machine provides appropriate tension to the tow before splitting. The tow then approaches the "splitting station" which is the most critical part due to the delicacy of the process and requires optimization. Considerable development in this research work has been conducted to improve this technique. The 12K carbon tow split into two equal halves and rewound into separate spools by the rewinding machine. Figure 2 illustrates virgin 12k tow and the split 6k tows which were produced after the splitting process.



**Figure 1.** Tow Splitting process line.

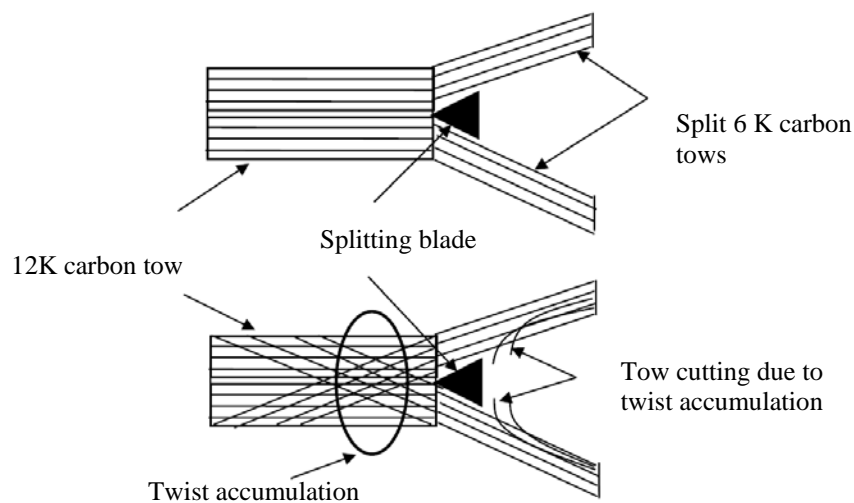


**Figure 2.** Virgin 12k and split 6k tows.

### 2.3. Development of Splitting Stations

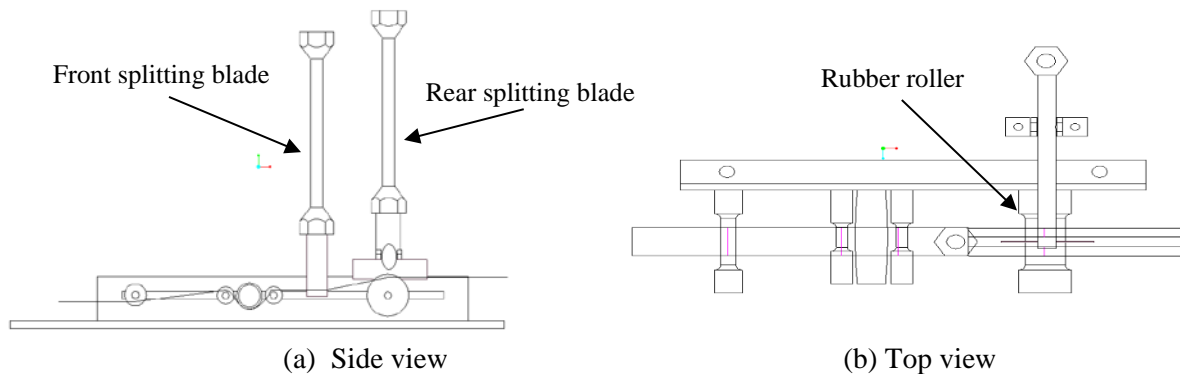
Preliminary investigation revealed that when the filaments are sliding across the blade a twist is formed in front of the blade. It was noted that the filaments are not perfectly aligned but cross over to each other, instigating twist accumulation as can be seen in the figure 3 demonstration. Similar phenomenon was also observed by the *Peter A. Kiss* et al in his patent[5]. To reduce these process limitations, following splitting prototypes were developed and tested:

- Pneumatic splitting system
- Static blade splitting system
- Automated tow splitting



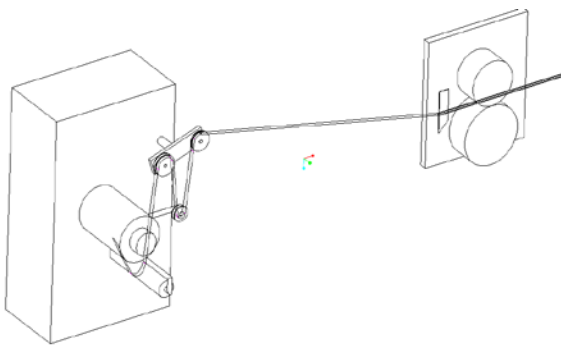
**Figure 3.** Splitting Phenomena of cutting and sliding.

**2.3.1. Pneumatic splitting system.** A combination of step and bulge roller were used to direct the tow in the centre of the splitting blade and spread the carbon tow respectively. The Splitting blades were attached to the pneumatic muscle which were controlled by the PLC (figure 4). During the splitting process, twist accumulated at the cutting edge of this blade which caused severe disturbance in the splitting process. As a solution the front blade was lifted to let the twist be cut by the rear lever-based blade. This technique did not produce the desired result. The rear blade made a sharp groove which trapped the filaments inside, causing the tow to wrap around the rubber roller. This also generated varied tension between the split tows; disrupting the splitting process and occasionally cutting off one tow.

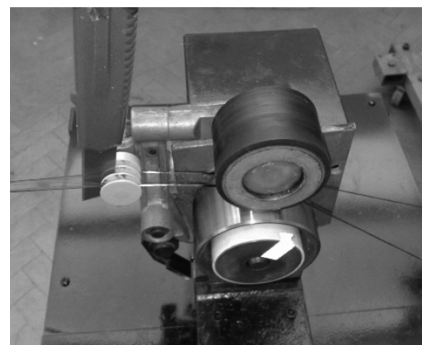


**Figure 4.** Pneumatic Splitting System.

**2.3.2. Static blade splitting system.** Another approach to splitting was considered by introducing a static blade next to the nip roller, which could be controlled manually in the event of uneven splitting (See figure 5 and 6). This procedure relied on the naked eye visualization and performed manually. The distance between the “spool unwinding machine” and splitting point was increased to reduce the twist intensity. A significant improvement was observed in the splitting process compared to the previous approach. With this approach, the issue of unbalanced tow tension was eliminated while the twist formation was reduced significantly. As the process was controlled manually there was a large variation observed which resulted in one spool weighing significantly higher than the other. This process concluded that this approach is applicable however the manual control of the splitting process is tedious, inconsistent and not appropriate for mass production.

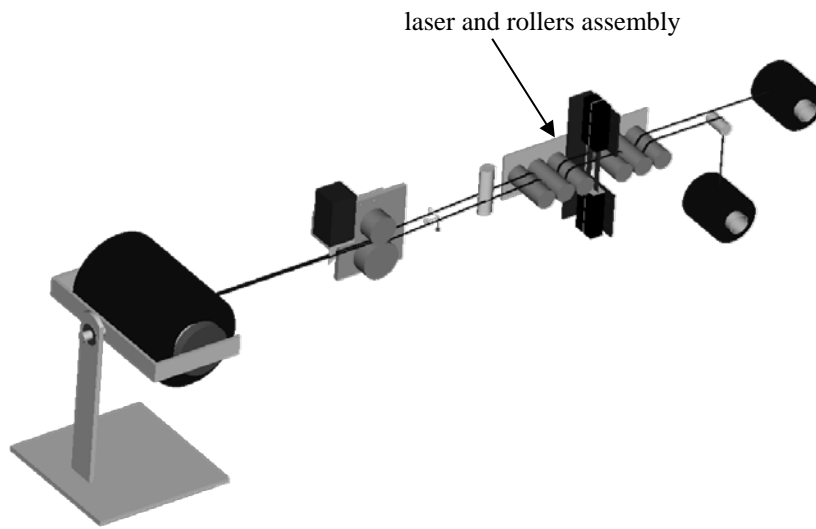


**Figure 5.** Static blade splitting system.

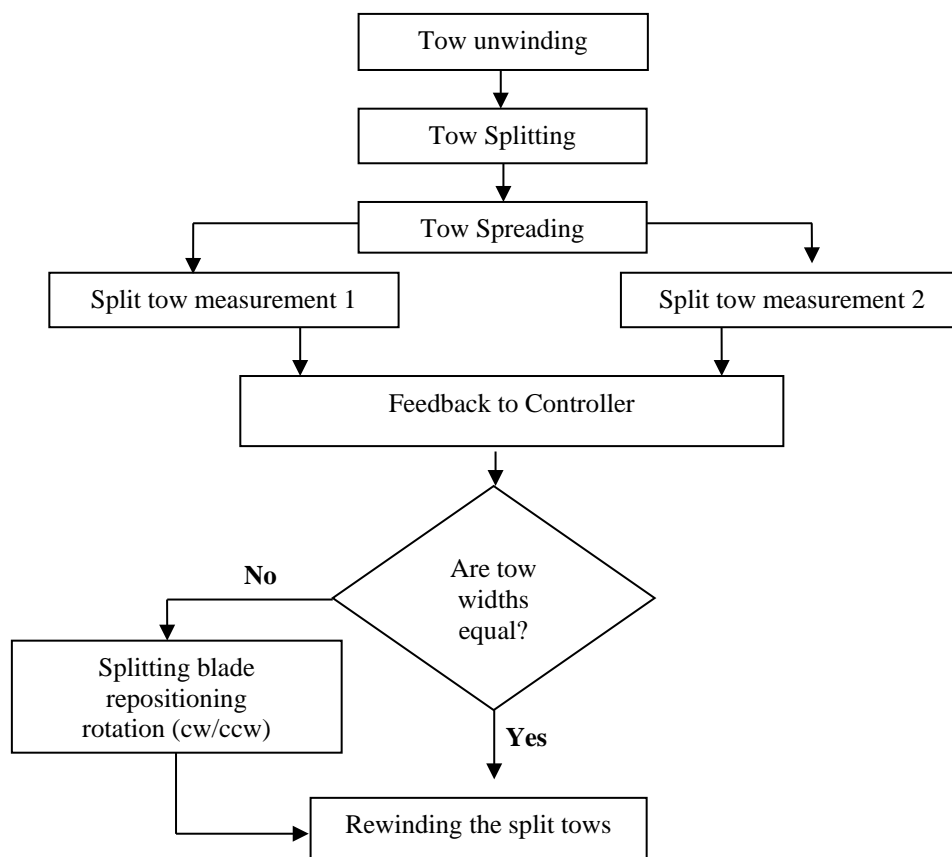


**Figure 6.** Nip roller and Static blade arrangement.

**2.3.3. Automated Tow Splitting.** Improvement on the manual system was made by replacing it with an automated PLC system which could control consistency of tow widths. The incoming carbon tow is split through the blade which is attached to the stepper motor. The split tows then approach the “laser and rollers assembly” station where they pass through the spreading and positioning rollers to ensure their correct position and widths with respect to the laser micrometre (see figure 7). The laser micrometers with a high frequency response are implanted between the set of rollers. It measures the split tow widths and their difference is used as a feedback to the stepper motor. If required, the PLC triggers a signal to the stepper motor to position the splitting blade (CW/CCW) accordingly to equalise the split tow widths. The process flow chart of the automated splitting process line is shown in figure 8.



**Figure 7.** Automated tow splitting with feedback system.



**Figure 8.** Process flow chart for automated tow splitting system.

#### 2.4. Software Programming

The automated tow splitting was controlled by the CoDeSys software. The stepper motor and the laser micrometres were configured to the input-output (I/O) module of the PLC. At program initiation; the stepper motor was home positioned (centre). The motor angular step values (one degree on each signal) was assigned in the “position set table” for the positive and negative movement. An angular limit was also placed to restrict the blade movement of more than 20 degrees; this is to avoid the movement of the blade to the point where one split tow could possibly cut off completely. The quality of the split tows is determined by using statistical tools. The sample data were recorded at every second and the data values were saved in the form of arrays. These values were exported to an Excel file where they were used to find the standard deviations and other statistical data.

### 3. Results and discussions:

#### 3.1. Quality of Split Tows

The quality of the split tows were considered for the static blade and automated splitting system only, as the pneumatic splitting system could not function for a reasonable length to be considered. The quality of split material was determined by the percentage weight difference between the split spools. Tow qualities for the automated splitting system were also determined statistically by recording the real time process data. Table 2 represents the weight difference of the split spools. It is observed that the split spools which are produced by the manual splitting have greater weight percentage difference compared to the automated splitting system. On average, this difference was 17.13 % for the manual splitting and 5.06 % for the automated splitting system. The reason of the higher weight difference, in manual splitting, was due to the lack of process control since the blade was moved manually. However, due to the continuous sensor feedback, the splitting on the tows were controlled effectively.

**Table 2.** Weight difference in 6k split spools.

|                            | Sample | Actual split spool weight |                | Difference             | Percentage difference |
|----------------------------|--------|---------------------------|----------------|------------------------|-----------------------|
|                            |        | S 1<br>(grams)            | S 2<br>(grams) | (S 1 – S 2)<br>(grams) | (%)                   |
| Manual splitting system    | 1      | 2114                      | 1560           | 554                    | 15.0                  |
|                            | 2      | 3332                      | 2324           | 1008                   | 17.8                  |
|                            | 3      | 1641                      | 1125           | 516                    | 18.6                  |
| Automated splitting system | 1      | 2809                      | 2594           | 215                    | 3.9                   |
|                            | 2      | 3015                      | 2717           | 298                    | 5.1                   |
|                            | 3      | 2211                      | 2021           | 190                    | 4.5                   |
|                            | 4      | 1756                      | 1562           | 194                    | 5.8                   |
|                            | 5      | 2747                      | 2434           | 313                    | 6.0                   |

#### 3.2. Statistical Analysis of Split Tows

The variation in the split tow is unavoidable. Hence, the overall quality of the split tows was determined statistically. The analogue values were recorded in real time as the split tows pass under the laser beam by PLC. These values were converted into the tow width by using the calibration curve equation. A total of 360 metres of tow length is recorded by the sensors at the speed of 0.6 metres per second. Hence, a total of 600 readings were taken. The proportion of split tows were used to determine the filament counts



as determined by equation 2 and 3. This is then multiplied by the total number of filaments as mentioned in equation 4 and 5.

Total Number of filament = 12000

Width of split tow 1 =  $X1_i$

Width of split tow 2 =  $X2_i$

Where  $i$  represent the number of recorded readings.

Total width of split tow 1 and tow 2 =  $Y_i = (X1_i + X2_i)$  (1)

Proportion of split tow 1 =  $T1_i = X1_i / Y_i$  (2)

Proportion of split tow 2 =  $T2_i = X2_i / Y_i$  (3)

No of filaments in split tow 1 =  $T1_i \times (12000)$  (4)

No of filaments in split tow 2 =  $T2_i \times (12000)$  (5)

Table 3 represent the statistical data of split tow in terms of filament counts. There is no significant difference in the mean value of the filament counts whilst the standard deviation is 0.68k. The filament counts distribution of both split tows can be assumed as normally distributed. The range of the split tows is approximately between 5k and 7K. The observed mean difference in filament counts is 227 and the standard deviation is 1.3k.

**Table 3.** Weight difference in 6k split spools.

|                    | Split tow 1 Filaments | Split tow 2 Filaments | Difference |
|--------------------|-----------------------|-----------------------|------------|
| Mean               | 6113                  | 5886                  | 227        |
| Standard Deviation | 684                   | 684                   | 1368       |

#### 4. Conclusion

The developed tow splitting system proved to be a very promising and successful technique to split carbon tows. This system provides an obvious cost reduction. The 12k carbon spool was split successfully by the automated system into 6k carbon spools. Almost no human interaction was required after setup. The splitting process was monitored by the laser feedback system. The sensitivity of the splitting blade was set to 0.02mm of the tow difference. Without the laser feedback system, on average, the difference of the split spools weight was 17%. However, laser feedback had drastically improved the performance of the splitting system to 4%. Currently, the split tow quality may not be up to the standard of the aerospace industry, but it has immense potential in automotive sector especially for short fibre preforming application.

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