NEW OPPORTUNITIES IN LIGHTWEIGHT SPREAD TOW FABRICS (STF) FROM CARBON TOWS OF 12K COUNTS

Fredrik Ohlsson, Product Manager – Materials
Nandan Khokar, R&D Manager
Oxeon AB, Borås, Sweden

ABSTRACT

A new and flexible method has been developed to produce lightweight fabric called Spread Tow Fabric (STF). It involves the steps of spreading a tow of higher count, e.g. 12k, into thin-and-wide Spread Tow Tapes (STT) and weaving them into a lightweight fabric by employing the novel tape-weaving technique. STF offers the advantages of relatively lower crimp and higher cover factor to result in improved mechanical performance, about 20-30% weight reduction of composite materials, enhanced draping ability and attractive aesthetics.

Through this route the traditional low areal weight woven fabrics produced using 1k – 6k tows can be replaced with even lower areal weight fabrics using 12k or higher tow. The carbon fiber producers thus have the opportunity now to deliver essentially a couple of tow counts, e.g. 12k and 24k, instead of producing a variety of carbon fibers in 1k – 6k tows. Doing so would increase fiber output, stabilize fiber prices, facilitate uniform quality and level out supply fluctuations. All these factors are important if CFRP should be considered for large volume applications like automotive.

Keywords: Spread Tow Fabric (STF), Spread Tow Tape (STT), Tape-weaving, Woven carbon fabrics, Lightweight reinforcements

INTRODUCTION

Lightweight reinforcement fabrics are demanded for reducing the weight of composite materials. A variety of carbon fibers are available and in different tow counts to accord flexibility for obtaining different areal weights of reinforcement materials. However, the development of Spread Tow Fabrics (STF), which are produced by spreading a tow, e.g. 12k, into a Spread Tow Tape (STT) and then using these tapes as warps and wefts in the tape-weaving process, has demonstrated that low areal weight fabrics can be also
produced using tow counts higher than 1k – 6k. Additionally, the STF offers improved mechanical performance, thinness, draping ability and even different aesthetics compared with those produced using 1k – 6k tows.

Besides the technical advantages that STF brings, this approach will also benefit the fiber producers in that they can focus on production of fewer tow counts and maintain a steady material production at steady cost. The need for changing production settings for manufacturing many different tow counts is thus minimized. Accordingly, this paper presents an outline of the newly developed method for producing lightweight high-performance woven material STF and also its advantages.

**RELEVANT ASPECTS OF AVAILABLE CARBON REINFORCEMENTS**

Continuous carbon fiber reinforcements are available in, among other forms, unidirectional (UD) tapes, non crimp fabrics (NCF) and woven fabrics. UD tapes are available in a wide variety of areal weights and constitute highly orientated fibers in only one direction. The unidirectional orientation of fibers makes its draping in complex geometries difficult because the UD sheet tends to split, wrinkle and fold, creating uneven fiber distribution.

NCFs provide either two-, three- or four-directional fiber orientations in one ‘sheet’ construction directly. The low areal weights achievable are dependent on the count of the tows (usually 3k to 24k) that are used to build up the layers of the NCF. However, NCF materials present difficulties in draping, particularly at sharp and tight bends, depending on stitch density and stitching pattern/style. This is because the stitches tend to lock the multi-directionally orientated fibers in their positions and thereby restrict the fibers from sliding past easily relative to each other to conform to the required draping geometry.

In comparison to UD tapes and NCF materials, traditional woven fabrics present fiber orientations in two mutually perpendicular directions and improved draping ability. However, such a woven material’s mechanical properties get lowered because of the inherent crimp that is introduced in the fibers due to the weave. To minimize the loss of mechanical properties arising from crimp, two things are considered. First, tows of low count, usually 1k to 6k, are used to keep the crimp angle as low as possible. Second, to reduce the frequency of the crimp, and also to enable gentler weaving of carbon fibers, the spacing between the constituent tows/yarns is increased. Different weave patterns such as twills and satins are also employed to achieve lower crimp frequency.
With 1k – 6k tow counts, the typical areal weights of woven reinforcements achievable are in the range of about 90 to 300 gsm. However, the low areal weight woven fabrics have correspondingly reduced cover factor and uneven fiber distribution. The fabric construction tends to be loose and exhibits gaps / openings (which is undesirable because filling gaps with matrix increases the dead weight of the composite material). Fig. 1 shows a typical carbon fabric of 95 gsm produced using 1k tow. Its low areal weight is due to its low cover factor and such a material is not relatively thin either. As a consequence, the composite material incorporating it would tend to be correspondingly heavier.

![Figure 1](image.png)

*Figure 1. Although a low areal weight woven fabric is obtained by using a low tow count, the open construction results in reduced fiber-volume fraction in the final composite material. (The picture is slightly enlarged to show the gaps.)*

As the carbon fibers get abraded and damaged easily during the weaving process compared with commonly used fibers like cotton, polyester, glass, aramide etc., there is a limit to how closely they can be packed in the fabric by the weaving process. Because low areal weight woven fabrics are somewhat open in construction, a number of fabrics have to be plied to close the gaps / openings. However, such plying causes the composite material to become relatively thicker (and also heavier) than actually necessary.
**FLEXIBILITY FROM CARBON FIBER PRODUCERS**

It is for enabling production of different areal weights of carbon reinforcements that the fiber producers are required to be flexible in producing different tow sizes. Table 1 shows available different tow counts of some commonly used carbon fiber products to reflect the flexibility in supply. However, such flexibility comes with increased production cost due to setting changes involved. Also, while fiber manufacturers would like to produce on a steady production plan, the fluctuations in market demands can at times upset those plans and cause uncertainty in supplies and costs for their customers.

Table 1: Tow count availability of different carbon fiber products

<table>
<thead>
<tr>
<th>Fiber producer</th>
<th>Fiber product</th>
<th>Tow counts available</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tenax</td>
<td>HTA40/HTS40</td>
<td>1k, 3k, 6k, 12k, 24k</td>
</tr>
<tr>
<td>Toray</td>
<td>T300</td>
<td>1k, 3k, 6k, 12k</td>
</tr>
<tr>
<td>Hexcel</td>
<td>AS4</td>
<td>3k, 6k, 12k</td>
</tr>
<tr>
<td>Formosa</td>
<td>TC33</td>
<td>1.5k, 3k, 6k, 12k, 24k</td>
</tr>
<tr>
<td>Mitsubishi Rayon</td>
<td>TR50</td>
<td>6k, 12k, 15k, 18k</td>
</tr>
</tbody>
</table>

Table 1 should not lead one to assume that low tow counts are produced for all carbon fiber types. There are many carbon fiber products which are available in only one tow count (e.g. T1000G (12k), M30S (18k), HS40 (12k), IM6 (12k), IMS65 (24k) etc.) and some in only two tow counts (e.g. M35J (6k and 12k), IM7 (6k and 12k), etc.). Obviously it is not possible for the converters (i.e. producers of woven materials, NCF and UD materials) to process many of these higher tow counts into high-performance and low areal weight reinforcements.

To make available so many different tow counts of a fiber type presents a challenge to the fiber producers because on one hand the fiber producers have to meet the varying demands of the market and on the other they have to consider uninterrupted production. Changing settings for producing different counts of tows involves considerable time and effort and causes production loss, which at times could be up to 30% in reference to installed capacity. As a consequence, it becomes difficult to run the productions steadily and there is fluctuation in fiber quality (between lots) and a drop in output. The loss in production has to be made up with higher prices for low tow counts (1k – 6k).

This situation can be improved if low areal weight reinforcements that are presently obtained using tow counts 1k – 6k are replaced by low areal weight reinforcements
produced using higher tow counts such as 12k or 24k. The fiber manufacturers could then have the possibility of running their production lines more steadily. As a consequence, the market would be also assured of non-fluctuating availability of fibers and lightweight reinforcements.

From the foregoing it follows that production of STF is relevant because a lightweight woven carbon fabric can be obtained using any fiber product that is available in tow count 12k or higher. The route of STF production is therefore outlined here. It comprises the steps of converting tows into Spread Tow Tapes (STT) and weaving such tapes into Spread Tow Fabric (STF). Its flexibility and technical advantages are also considered.

**Production Route of Spread Tow Fabric**

Production of high-performance and lightweight woven carbon fabric using higher tow counts, like 12k and 24k, involves two steps. In the first step one, or more, tow of higher count is subjected to a spreading action whereby the constituent filaments are displaced laterally and a thin-and-wide Spread Tow Tape (STT) is produced. The spreading action can be controlled to obtain a set width of the STT, usually from 20 mm and above. Thus, the same tow can be spread to different widths, within certain practicable limits, and thereby correspondingly different areal weights of STT can be realized. To enable handling of STT, it is stabilized and wound into spools. It is commercially available as TeXero® UD tapes in the range 38 to 200 gsm.

The subsequent step involves production of STF by weaving STT as warp and weft. A newly developed weaving technique, called tape-weaving, is employed for producing STF. This is because the conventional weaving equipment is unsuitable for processing STT as it is essentially designed for handling yarns, and not tapes. Spools of STT are mounted on the tape-weaving machine and directly used as warp and weft in carrying out their weaving. The developed tape-weaving machine can process tapes of widths 20 to 50 mm as warps and wefts. The produced woven fabric, called the Spread Tow Fabric (STF), is commercially available in plain weave as TeXtreme® in the range 76 to 400 gsm and is produced using 12k and higher tows. Twill weave pattern is also producible by the tape-weaving method.

It is pertinent at this point to indicate the low areal weights achievable with STF in relation to the traditional woven fabrics that are produced using tow counts 1k – 6k. Table 2 below compares the typical areal weights of traditional woven fabrics and STF. As
can be observed, for the three different fiber types indicated, an STF produced using STT of 12k tow can be made lighter than those produced using 1k-6k. Thus, the entire range of areal weights that are producible by using 1k-6k tows can be replaced by STF. The indicated areal weights of STF in the Table 2 below are achievable with the present technology. In future, production of even lighter areal weight fabrics from 12k STT cannot be ruled out.

Table 2: Comparison of approximate areal weights

<table>
<thead>
<tr>
<th>Fiber Type and Tow Count</th>
<th>Traditional Woven Fabrics - gsm</th>
<th>Spread Tow Fabrics - gsm</th>
</tr>
</thead>
<tbody>
<tr>
<td>HS - 1k</td>
<td>90 – 120</td>
<td>not applicable</td>
</tr>
<tr>
<td>- 3k</td>
<td>200 – 400</td>
<td>not applicable</td>
</tr>
<tr>
<td>- 6k</td>
<td>300 – 500</td>
<td>not applicable</td>
</tr>
<tr>
<td>- 12k</td>
<td>500 – 600</td>
<td>80 – 400</td>
</tr>
<tr>
<td>IM - 6k</td>
<td>200 – 400</td>
<td>not applicable</td>
</tr>
<tr>
<td>- 12k</td>
<td>300 – 400</td>
<td>135 – 250</td>
</tr>
<tr>
<td>- 18k</td>
<td>not available</td>
<td>75 – 300</td>
</tr>
<tr>
<td>- 24k</td>
<td>not available</td>
<td>80 – 300</td>
</tr>
<tr>
<td>HM - 6k</td>
<td>200 – 500</td>
<td>not applicable</td>
</tr>
<tr>
<td>- 12k</td>
<td>300 – 500</td>
<td>130 – 245</td>
</tr>
</tbody>
</table>

The tape-weaving process was first demonstrated and described by Khokar [1, 2]. The initial properties of STF were subsequently presented by Ohlsson and Khokar [3]. Tsai [4] has also studied similar ‘thin ply’ fabrics. STF has been well received by the market because it offers improved mechanical performance and/or reduced weight of composite materials by up to 20 – 30%, thinness, good draping ability, improved surface smoothness and a different chequered appearance.

**ADVANTAGES OF STF**

The advantages of STF are best explained by referring to Fig. 2, which illustratively compares the constructional difference between the traditional woven material produced using tows and the STF produced by the tape-weaving process using STT. The important technical advantages of STF become clear from the following:

- Fiber straightness due to virtually no crimp improves the mechanical properties.
- Flatness of tapes increases cover factor and makes the fabric relatively thinner leading to higher exposure of fibers for wetting.

- Reduced amount of gaps at interlacing points reduces matrix accumulation and thereby dead-weight of composite material.

- Long and straight fiber floats, due to use of wide tapes, enables fibers to slide easily and distribute well in tight corners and sharp bends to result in improved draping characteristics.

- Parallel fibers and flatness of the tape makes the surface smooth and glossy.

- Chequered look makes the fabric aesthetically different from the traditional materials.

Figure 2. Compared to woven fabrics produced using tows, the STF combines flatness, thinness, improved performance and smoothness at the same time with good draping ability.

The production of STF by tape-weaving is advantageous because the effort and time required for handling and controlling scores of tows in the conventional weaving process are obviated. The production of STF requires a relatively few STT spools, depending on the tape width to be used and the fabric width to be produced. The STT could be obtained directly from a couple of bobbins for a given fabric production. To exemplify, a 50 m² STF can be directly woven from a single bobbin having 5000 m length and 12k tow count by converting it into an STT of 20 mm width and weaving them by the tape-weaving process. Obviously, such a route brings flexibility into the conversion step and is advantageous for short production runs too.
Accordingly, the need to handle only a few STT spools for carrying out weaving lends itself to a new flexibility in that the weavers can consider tows in terms of weight, instead of number of bobbins each of specific length. This flexibility becomes apparent when production of conventional woven tows is compared to that of STF. While 50 m$^2$ of STF having 1m width could be produced using 20mm wide STT that is obtained from one 12k bobbin of 5000 m length as exemplified above, the conventional tow woven reinforcement would require at least 200 warp bobbins of 3k count to produce the same width of material. And the number of bobbins that would be needed for weft cannot be ignored.

**FLAT TOW FABRICS**

The relevancy of STF can be appreciated from the fact that there are products available today that are closer to it, such as flat tow woven fabrics, filament wound cylinders and multidirectional flat tow NCF, which are widely manufactured and used. However, STF and flat tow fabrics/products are structurally different. To exemplify, in the production of a flat tow woven fabric, the tows are woven as they are, i.e. without spreading the tow. Fig. 3 shows a comparison between the woven flat tow reinforcement and and STF. The flatness of the tow corresponds to what is delivered on the bobbin. Khokar and Ohlsson [5] have discussed the technical aspects of the flat tows and spread tow fabrics.

![Figure 3. The tows in a flat tow woven reinforcement (left) are not spread and therefore are narrower in comparison with those in STF (right).](image-url)
The production of STF goes a step further than that of flat tow weaving, as also filament winding and NCF production, in that the spreading of tow is involved. Whereas the typical areal weight of a ‘flat tow’ woven fabric made using 12k tow is in the range of about 160 to 350 gsm, the areal weight of the presently available STF starts at 76 gsm. The flat tow weaving also involves traditional creeling, drawing the tows through healds and reed etc. These operations are not required in the production of STF.

**Adding Value to Carbon Fiber Products**

The possibility of manufacturing STF provides a new opportunity to directly control the production of fabrics of different areal weights without changing the tow counts. At the same time, engineering of new attributes to improve the fabric’s performance is also achieved as indicated earlier. Another interesting aspect of STF production is that STT of different areal weights, and either same or different widths, can be also combined in the same STF to engineer a reinforcement material for achieving specific performance characteristics in warp and weft directions of the STF according to application demands. The possibility of producing STF is considered to be economically beneficial for the fiber producers. Olofsson [6, 7] proposed that carbon fiber producers could consider production of only heavy tow counts (12k and higher) so that they could maintain a steady production (i.e. without having the need to keep changing productions of many different tow counts). He further reasoned that the need for producing tows of low counts 1k-6k was becoming less relevant for manufacturing lightweight woven fabrics. This was because such lightweight woven fabrics are anyway becoming available now by spreading tows of a higher count, e.g. 12k and 24k, into STT, and weaving STT by the tape-weaving process into STF.

In the light of STF development, and because fibers are made available on weight basis, the fiber manufacturers could consider optimizing their existing capacities without major investments (as in setting up of new lines and plants). Making a steady availability of 12k and 24k tows and lightweight woven reinforcements in the form of STF could perhaps be a way to satisfy the large volume market like that of automotive.
CONCLUSIONS

Production of Spread Tow Fabric (STF) makes available lightweight woven carbon fabrics. STF is producible using higher tow counts, such as 12k, in two steps. In the first step, a tow is spread to obtain the Spread Tow Tape (STT) which is then used as warp and weft in the tape-weaving process to produce STF. Compared with the woven fabrics produced using tows, the STF exhibits improved mechanical performance, thinness, draping ability and aesthetics. The conversion of tows to tapes helps in reduced material requirement and handling besides adding a new value to carbon fiber products. The possibility of making available STF could perhaps be a way to satisfy the large volume market like that of automotive.

ACKNOWLEDGEMENTS

Sincere thanks are expressed to Mr. Henrik Olofsson, CEO, Oxeon AB, Sweden, for his encouragement and support at all times.

REFERENCES