CARBON FIBRES – LATEST DEVELOPMENTS, APPLICATIONS AND USE OF TEXTILE PROCESSING

The growth in polyacrylonitrile (PAN) based carbon fibre production since its inception in the 1970’s has been phenomenal. What was then considered a speciality material, is now produced globally with supply and demand increasing steadily as shown in Figure 1.

![Carbon Fibres Market Overview](chart.png)

**Figure 1 Historic overview of carbon fibre demand and capacity**

Carbon fibres are produced by the thermal degradation of polyacrylonitrile (acrylic) fibres, specially produced for the carbon fibre industry. Most standard textile acrylic fibres, do not have the required comonomers and finishes suitable for thermal processing. Courtelle, from Bluestar, UK is one exception to this and can be converted to a lower cost carbon fibre for less critical applications. Figure 2 shows the principle of carbon fibre manufacture.

![Manufacture of acrylic precursor, carbon and oxidized fibres](flowchart.png)

**Figure 2 Manufacture of acrylic precursor, carbon and oxidized fibres.**

(Courtesy of Teijin, Japan)
Most carbon fibres are supplied on spools of up to 15 kg weight. Typical nomenclature is the number of continuous filaments in a single yarn or tow, this usually abbreviated to the K number where K = 1000s of filaments. Tows are traditionally supplied with filament counts of 1K, 3K, 6K, 12K, 24K, 40K and 50K. Larger tow counts, 160K and 320K and oxidized PAN fibres, are usually plated into cartons. Figure 3 shows the typical range of mechanical properties of currently available carbon fibres.

**Figure 3 Carbon Fibre Mechanical Properties.**

Note: (1) Tensile properties of carbon fibres are usually quoted in engineering units (Pa)
(2) Tensile modulus is normally considered to be absolute, carbon fibres being totally elastic to break, unlike other fibres which have an initial modulus, followed by deformation after reaching yield point.

**Figure 4 Load/Elongation Curve of a typical standard modulus carbon fibre.**
Conversion of carbon fibres to composite materials typically requires taking one dimensional continuous filament tow and making a two dimensional “sheet” of carbon fibres, bonded with a resin type substrate. Cut the shape required and layer the sheets to make a three dimensional carbon fibre composite. The 3 dimensional product is then cured and a lightweight, strong and stiff composite is produced.

A traditional process to convert carbon fibres to a two dimensional, resin impregnated sheet is *pregregging* (short for pre-impregnation).

![Figure 5 Principle of the production of carbon fibre prepreg.](image)

As seen in figure 5, a creel loaded with carbon fibre tows is formed into a sheet, typically up to 1m width. Release paper is then coated with a film of resin. The band of tows is then brought onto the resin coated paper and a second release paper applied on top of the tow band. This is then run between squeeze rollers to impregnate the resin into the fibres. A heating facility and further pressure rollers can then be applied depending on the resin type and application. The upper layer of paper is then wound off and a paper/fibre/resin sandwich, or prepreg, is then wound up and collected.

![Figure 6 Creel of carbon fibre tows and prepreg winding](image)

Prepregs are a two dimensional array of carbon fibre and resin. As the impregnated tows are all parallel with each other, dimensionally stable composites have to be formed by laying the prepregs sheets at different angles in the final structure.
Figure 7 Angularly layered prepreg sheets form a stable 3-D composite

Due to the complexity, high product wastage and high labour time of conventional composite manufacture, the industry developed the technologies of “fibre placement” where the fibres are placed in the required format of the end composite before being impregnated with resin. Textile technologies have been used and are still being developed to meet this requirement.

Weaving
Plain weave was first used to create a cloth with equal reinforcement in the warp and weft direction. The fabric was woven, then impregnated with resin to make a prepreg. Other weave patterns then followed, such as twill weave were the fabric has less crimp, due to less intersections of warp and weft. Satin weaves were developed to have even fewer intersections of warp and weft, enabling a flatter fabric, easier to impregnate.

Figure 8 Plain, Twill and Satin weaves

Different weaving structures enable carbon fibre to be accurately pre-formed depending on the final application, before resin impregnation. Other weaving styles such as basket, leno, mock leno and 3 dimensional weaving are also used.

Hybrid fabrics can be easily produced by weaving. Here the final application may require a mixture of the properties of carbon fibre and for example, glass or aramids.

Figure 9 Hybrid fabrics of aramid/carbon and glass/carbon
As well as extensive application in aerospace structures, decorative carbon fibre composites are found to have a strong market presence. Here the composites are made not for reasons of mechanical performance, but because of their aesthetic value. Weaving is extensively used in these products.

![Figure 10 Woven carbon fibre parts used for aesthetic applications (Furniture, cell phone cover, car hood)](image)

Interestingly, The Japanese advanced fibre manufacturer Teijin, also complement their Tenax range of carbon fibres with a black pigmented aramid fibre, usually referred to as “Black Twaron”.

![Figure 11 Twaron aramids from Teijin, pigmented black and conventional yellow](image)

Carbon fibres use other textile processes such as braiding (tubular fabrics) carding and felting (for random orientation felts), knitting (warp and weft) for making composite preforms.

![Figure 12 Carbon fibre braiding, felt and knitted products.](image)
Textile developments in carbon fibre products.

Thinner carbon fibre fabrics – Stretch broken yarns.
Making thinner carbon fibre fabrics, for specific applications, is not as easy as simply producing finer tow counts. As the linear density (g/m) of the carbon fibre tow decreases, the cost per kilogram of manufacture increases dramatically. To overcome this, efforts have been made to produce thinner yarns and fabrics from standard products such as 12K (800 tex) tow. The idea of taking continuous carbon tows and breaking them into short “staple” fibres and then aligning and spinning into yarns first appeared in the mid-to-late 1980’s, to meet the growing demand for faster and automated manufacturing. A flat preform of aligned discontinuous fabric, for example, could be pulled via vacuum into a complex tool, obviating the need for hand layup methods.

Dr. Guenther Jacobsen, retired senior staff scientist who headed the SBCF (stretch broken carbon fibre) program for Hexcel, explains: “The stretch-broken carbon fibres give the material a pseudoductility akin to metals that makes it much easier to form complex parts. With SBCF materials, manufacturing costs can be reduced, and the number of composite parts on an airframe can be significantly increased.”

Figure 13 Continuous filament carbon fibre is stretch broken and spun into a finer staple fibre tow.

Spread carbon fibre tow

Technologies have been recently developed to take a standard continuous filament carbon fibre tow and spread it many times its width, using a propriety process as shown below.

Figure 15 Principle of thin fabric manufacture using tow spreading
Contribution to the environment – carbon fibre and textile processing

Carbon fibres were long considered a speciality product, destined for use in aerospace and other critical applications. However explosive growth in carbon fibre production combined with increasing demand for lightweight reliable products, especially in the automobile industry, makes an unending stream of new possibilities.

Carbon fibre composites were long considered too expensive for use in mass produced cars when compared to metals. The increased cost of the vehicle did not offset the increase in fuel efficiency from using lighter composite materials.

BMW in Germany looked at the whole concept of mass transportation including the ever increasing pressure to find zero emission vehicles. The result was a complete rethink of car production, the use of electric power instead of burning fossil fuels and the need to maintain car performance. The result was the zero emission BMW 3i series of electric cars. Lower weight obtained through the use of carbon fibre composites, enabled a larger battery to be installed, increasing the performance of the car.
Process of carbon fibre composite manufacture for the BMW 3i car.

Video at YouTube: https://www.youtube.com/watch?v=ka0q8Mc4xxw