WHITEPAPER

CARBON FIBRE PRODUCTION AND ITS ROLE IN MODERN ELECTRIC VEHICLES

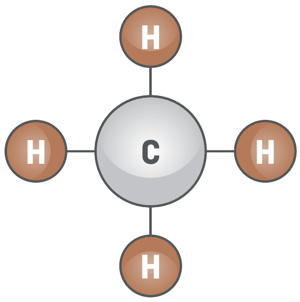
WHY CARBON?

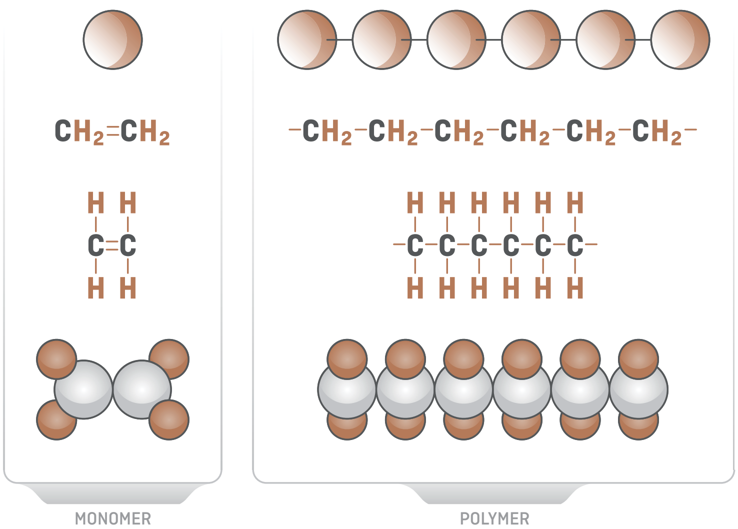
The incorporation of carbon in the automotive sector is not a recent development; it has a history rooted in Formula 1. The emphasis in Formula 1 revolves around speed, where weight serves as a critical factor limiting speed. Consequently, engineers in the racing realm consistently seek advancements in materials that are both lighter and stronger. Carbon, initially originating from the Aerospace industry, was introduced as a solution to address this need and has since been seamlessly integrated into the broader automotive industry.

However, achieving top speed is not a priority in the development of buses, and as a result, the use of carbon was not yet incorporated. This however changed with the introduction of electric vehicles bringing forth the necessity to cover longer distances with fewer batteries. Balancing the weight of the batteries required a lighter bus body, prompting the need for materials to be employed in the most efficient manner. While steel is strong and durable, it is much denser and heavier compared to carbon fibre. Achieving the same level of strength as carbon fibre would require a significantly greater amount of steel, resulting in increased weight.

A POLYMER CHARACTERIZED BY STRENGTH

Carbon fibre can be made from two source materials: Pitch-based or PAN-based carbon. PAN stands for Polyacrylonitrile and PAN based materials are used in consumer goods such as automotive. The Pitch based carbon exhibit exotic properties and are used in application where extreme properties are required and cost is of limited importance such as satellites and Mars mission vehicles, Polyacrylonitrile (PAN) is the precursor material for carbon fibre, and originates, just as most other plastics, from petroleum. There are however developments to create carbon precursor material from renewable resources.

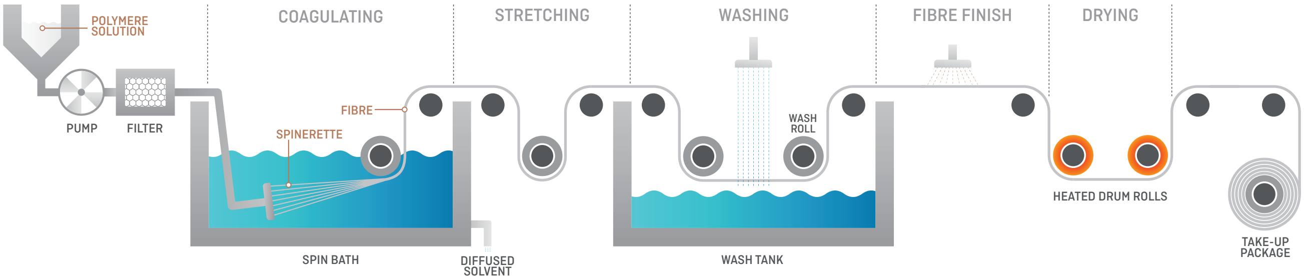




For both the petrol based as well as for the renewable polymer the process begins with polymerisation. Polymerisation is a chemical process through which monomers (small, simple molecules) are chemically bonded together to form a large, complex structure called a polymer. Polymers can differ and have a wide range of properties.

The monomers, which function as small building blocks, will be linked together to form the polymer. In the case of PAN, the chosen monomer is acrylonitrile.

Acrylonitrile monomers undergo a chemical reaction known as polymerisation. The polymerisation process begins with an initiation step. Initiators, which can be chemical compounds or other sources of energy, activate certain sites on the acrylonitrile molecules. This activation makes the molecules more reactive. This reaction involves connecting the individual monomers to form a long chain polymer. The resulting PAN polymer can be processed into a powder form. The PAN powder, once obtained, serves as the precursor material for the production of carbon fibres. It undergoes further processing steps, including spinning, stabilisation, and carbonisation, to transform it into high-strength and lightweight carbon fibres used in various industrial applications.



THE PROCESS OF FORMING FIBRES

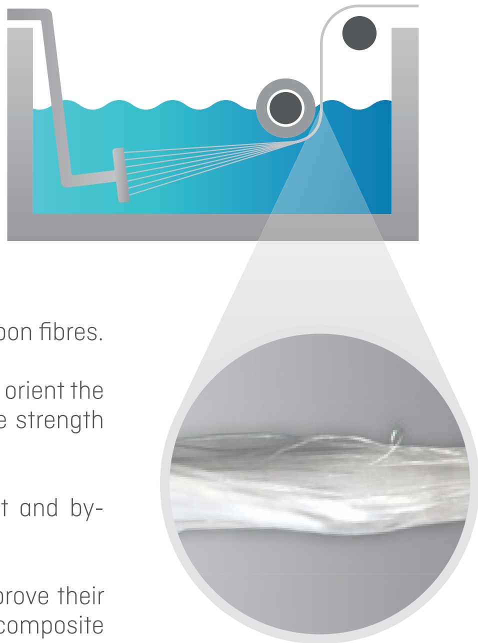
Polyacrylonitrile (PAN) powder is transformed into carbon fibres through a series of steps.

STEP 1: PAN POWDER DISSOLUTION

This process involves the dissolution of PAN powder, consisting of Polyacrylonitrile in powdered form. The PAN powder is dissolved in a heated liquid. This liquid is typically a solvent that helps dissolve PAN, creating a viscous solution.

STEP 2: SPINNING FILAMENTS

Following dissolution, the dissolved PAN solution is then filtered to remove any impurities or undissolved particles. The filtered solution is then passed through a spinneret, a device with tiny holes, to form continuous filaments. The spinneret shapes the liquid into long, thin threads.



STEP 3: TREATMENT PROCESS

The formed filaments go through a series of treatments to convert them into carbon fibres.

Stretching: During the stretching process, the filaments experience stretching to orient the polymer chains and align the molecular structure. This stretching enhances the strength and stiffness of the fibres.

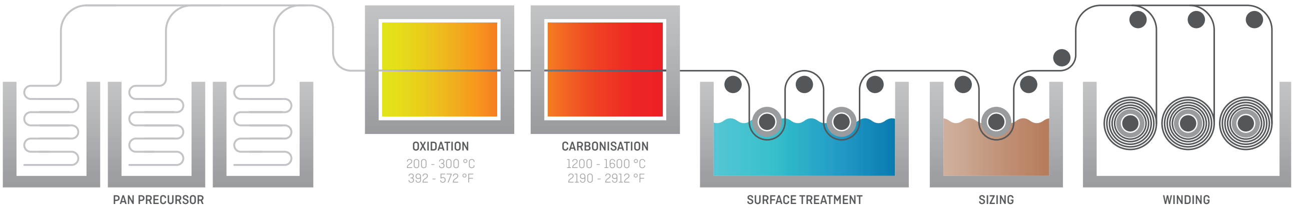
Washing: The stretched filaments are washed to remove any residual solvent and by-products from the spinning process.

Fibre Finish Application: A finish, often a coating, is applied to the fibres to improve their handling, protect against damage, and enhance adhesion with other materials in composite applications.

Drying: To conclude the treatment process, treated filaments are dried to remove any remaining moisture.

STEP 4:

The dried filaments are then subjected to a series of high-temperature ovens in an oxidation process.



During oxidation, the filaments are exposed to air at elevated temperatures. This step converts the PAN molecules into ladder-like structures,formingoxidised PAN (OPAN). The oxidation process is crucial for creating the precursor material needed for carbonisation.

STEP 5:

The oxidised PAN fibres are then taken through additional ovens, but this time in an environment without oxygen (or in an inert gas atmosphere). This high-temperature treatment, known as carbonisation, causes the removal of non-carbon elements, leaving behind a fibre composed mostly of carbon. During these heating processes, the Carbon fibres turn from white to black.

STEP 6:

After the carbonisation step, the carbon fibres may undergo additional treatment to enhance their properties and make them more suitable for specific applications. After surface treatment, the carbon fibres are wound onto bobbins.

CARBON BRAIDING

Carbon braiding involves interlacing carbon fibres in multiple directions to create woven structures. This technique enhances structural integrity, allows for tailored fibre orientation, improves impact resistance, and provides strength. The process utilises a specialised braiding machine to interlace carbon fibre tows. Throughout the braid, there are several longitudinal tows and tows in both 45 degrees directions. These longitudinal tows are there to create bending stiffness. The wires positioned at 45 degrees create torsional stability. Multiple braided layers can be applied depending on the application and therefore required stiffness and strength. Waste material that is left from this process, can be reused in other parts since the carbon fibres do not lose their properties. Carbon applications can for example be found in the aerospace and automotive industry.

WORLD'S FIRST BUS WITH A COMPOSITE MONOCOQUE

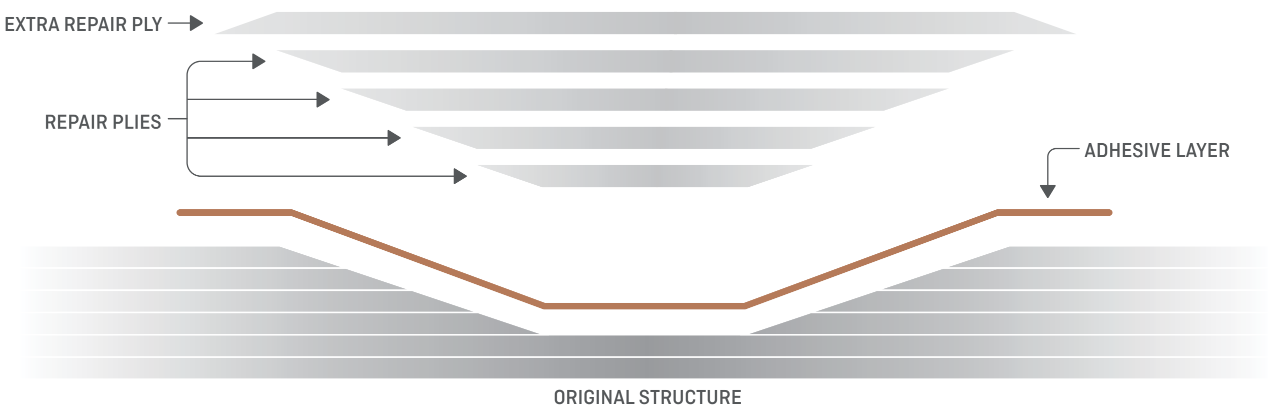
As for The Ebusco 3.0, which has a complete composite monocoque, the carbon braided beams undergo a transformation into a composite. Composites, by definition, are materials formed by combining various materials. In essence, a composite is a type of hybrid material consisting of two or more components of materials, which together provide the desired material properties. Therefore, the term "composite" doesn't specify the actual materials used; rather, it denotes a category of materials. In general, structural composites consist of fibres, predominantly glass, aramid, and carbon, along with a resin, primarily epoxy or polyester.

For the Ebusco 3.0, the structures are created out of carbon fibres and resin injection, the rest of the casco composites are formed with glass fibres and resin injection.

COMPOSITE REPAIR

Buses can drive millions of kilometres throughout their lifecycle and the good thing of composite materials is that they have exceptional repairability. The aerospace industry, in particular, boasts extensive expertise in conducting structural repairs on components like wings and fuselages. Similarly, in the wind turbine sector, blades undergo repairs as necessary, showcasing the versatility and effectiveness of composite material repair techniques. The same applies to the composite body of the Ebusco 3.0.

A damaged area can be cut out of the body and replaced by a new section. After cleaning the damaged area, compatible materials for repair need to be selected, including the right resin and reinforcing fibres. These materials will be applied to the damaged section, ensuring proper layering and alignment. When a prescribed tapered overlap is created between old and new sections, the strength and stiffness of the original structure can be restored with no or neglectable added weight.



THE EFFECT OF COMPOSITE

But what are the results of these efforts. The Ebusco 3.0, a 100% electric bus with a full composite casco with a weight reduction up to 5,000 kilograms has a consumption of 0.65 kWh per kilometre in normal climate conditions. This consumption enables the bus to drive up to 700 kilometres on a single charge, leaving no more excuses to not drive zero emission.

With multiple Ebusco 3.0 models on the road, and many more to come, this approach is proving itself to be highly efficient and therefore suitable for the challenges the transition to zero emission brings.

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