The manufacture of carbon fibre engineering essay

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In the evolution of materials one can strongly agree that science and engineering has played a crucial role into finding new man-made materials. The requirements and living standards currently has advanced thus forcing researchers venturing into development of complex materials. Figure 1 illustrates the relative importance with respect to time and its rate of development during that period. It is noticed that there was drop in development of materials in between 1940 to 1980. As time passed, many researchers understood materials intensely and there was an increase in materials development. http://3. bp. blogspot. com/-fxxATdhPhTI/TXK2DbsluwI/AAAAAAAAAd0/xFZwKUz1GOc/s1600/materials. JPG

Figure – Evolution of materials, http://smart-materials. blogspot. sg/2011/06/evolution-of-engineering-materials. html

Composite materials is an area of focus recently researchers explore to develop an innovation to cater to quick changing lifestyle and technology. One of the most commonly known and successful complex composite material is Carbon Fibre. Carbon fibre is recognized for its extraordinary mechanical properties such as strength, stiffness, exceptional fatigue features and most importantly its light weight density. Carbon fibre composites has brought revolutionary change and improvement in many industries such as automotive, aerospace, sports, defense, construction and many others. Globally there has been an increase in the use of carbon fibre composites as shown in figure 2[1]. Future prediction for an increase in consumption and production can be made by analyzing these figures.

Figure – Estimation of Carbon Fibre Consumption[1]

Carbon fibre is a very thin strand of material with a diameter of 50-100nm. It comprises of mostly carbon atoms which are bonded in microscopic crystals that are aligned parallel to elongated axis of the precursor. The alignment of the crystal on the fibre increases in strength for its size. Many carbon fibres are collated together to form a yarn and followed by woven as a fabric. The fabric is molded into shape and coated with epoxy to form as a composite material for different applications.

Carbon fibre is categorized into three different categories such as high performance(HP), general purpose(GP) and activated carbon fibres(ACF). High performance carbon fibre has properties of high strength and modulus. General performance carbon fibre has properties of low tensile strength, low tensile modulus and as compared to the rest it is low in cost. Activated

carbon fibre basically has the presence of large number of micropores which enables acceleration of carbon atom absorption. Generally, carbon fibre can also can be classified as in terms of its tensile strength and modulus such as ultra-high modulus, high modulus, intermediate modulus, low modulus and high strength [2].

During manufacturing process of carbon fibres, there are a few types of precursors that can be used to make carbon fibres. These raw materials are Pitch fibres and Polyacrylonitrile(PAN) fibres. The different types of precursors also determine the type of carbon fibres available in the market as their mechanical property vary.

There is relatively a substantial amount of difference between PAN and Pitch type carbon fibres. PAN is the most common type of carbon fibre that is used worldwide and is leading in the carbon fibre market. It is mainly used by companies due to its combination of mechanical properties particularly in high tensile strength and flexibility [5] whereas pitch based carbon fibres have good tensile strength, stiffness, excellent thermal and electrical conductivity. Pitch on the other hand is slowly increasing its production due to its high carbon content and low cost availability.

Table 1 shows the cost of precursors and cost of carbon fibers in 1980s [6]. PAN based carbon fibres were more expensive because of its high tensile strength therefore it is understood that the higher the tensile strength the higher the cost of carbon fibre.

Table – Cost of precursor/carbon fibres

Cost of precursor($/kg)

Cost of carbon fibres ($/kg)

PAN-based

0. 40

60

Isotropic pitch-based

0. 25

22

Manufacturing of Carbon Fibre

The manufacturing processes of carbon fibre is an in-depth understanding of both chemical and mechanical processes. It consists of processes such as polymerization, melt-spinning/wet-spinning, carbonization and graphitization. These carbon fibres are fabricated either by pitch fibres or polymer fibres which are also known as polyacrylonitrile (PAN). PAN and Pitch are precursors that are available in short and continuous form [1]. Pitch precursors are usually attained from residues of the distillation of crude oil. PAN precursors are in the form of textile fibers that leave a residue of carbon. Below shows a standard process for making carbon fibre from PAN or Pitch precursors.

The precursors would have to go through common phases such as carbonization and graphitization as shown in the figure above(shaded in grey). However, before this phase, different precursors have to go through their own preparatory phase before proceeding to carbonization. For pitch

precursors, it has go through pitch preparation (isotropic/anisotropic), melt spinning and infusibilization. Whereas for PAN precursors, it has to undergo polymerization, wet-spinning and stabilization before proceeding to carbonization.

Carbonizaton and Graphitization

The two main processes that gives the excellent mechanical properties of carbon fibre is carbonization and graphitization. Carbonization or controlled pyrolysis is the process that the different type of precursors go through to obtain the final form of carbon fibre. The process consist of heating the precursors at high temperatures without the presence of oxygen. The absence of oxygen keeps the fibre from not burning out at high temperatures. During this phase, carbonization is to remove the impurities or rather non-carbon atoms in the precursor such as hydrogen, nitrogen, carbon dioxide, carbon monoxide and etc [7]. The weight of the fibre reduces to 50% as the impurities are exhausted out from the fibres [1]. This takes place at temperatures in between 500 to 1500 degree Celsius where the graphite structure transforms in the lateral direction by intermolecular cross-linking. Graphite structure transformation results in the increase in modulus and fiber density but decreasing in fibre diameter.

Graphitization is an optional process if there is a necessity to accomplish better mechanical properties. This process takes place at temperatures more than 2000 degree celcius in an inactive atmosphere usually nitrogen or argon. This process allows the fibre to be more graphitic with the increase in crystalline size and ordered orientation[1]. However these two processes, carbonization and graphitization, only takes place after the precursors have

been through stabilization for PAN or infusibilization for pitch. Stabilization or infusibilization is done before carbonization to prevent fusing and melting during the high temperature heating process.

Carbon Fibre from pitch precursor

Pitch precursor are either obtained from petroleum or coal after intense distillation processes. It is known that coal pitch is more aromatic that petroleum pitch[9]. However coal pitch had more solid content which will not be favourable for heat treatment as it will cause premature breakage. Pitch can also be obtained from man-made polymers or also known as synthetic polymers by undergoing a process called pyrolysis. High purity and faster rate of stabilization process has given synthetic pitch a keen interest over the other pitches.

There are 2 categories of pitch precursor known as isotropic and mesophase pitch. Isotropic pitch is catered for general-purpose carbon fibre whereas the mesophase pitch is catered for high performance carbon fibre [2].