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PITCH-BASED CARBON FIBERS: PREPARATION AND APPLICATIONS

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ABSTRACT

Attention to carbon fiber (CF) conditioned by their unique physicochemical, mechanical and electrical properties, which makes them in demand in various fields of activity. Today there are several kinds of carbon fibers, most of which (about 90%) are made of polyacrylonitrile (PAN). Even though carbon fibers are produced from several types of different precursors, their widespread commercial use is limited by the high cost of the product. Has, many research and engineering groups sought to reduce the cost of production by using cheap carbon raw materials. A likely solution to this problem is the exploitation of coal, petroleum, and coal tar as an effective progenitor for CF production. This review discusses neoteric accomplishment in CF synthesis using various carbon pitches. The possibility of obtaining carbon fibers based on resin with the addition of PAN is presented, and the prospects for their use in energy storage systems and various reinforced composite materials are described in detail.

Keywords: carbon fibers, coal tar pitch, petroleum pitch, mesophase pitches, isotropic pitches, nanomaterials.

1. Introduction

Carbon nanomaterials (CNM) like as: carbon fibers (CF), activated carbon (AC), nanotubes (CNTs), graphene (Gr), carbon quantum dots (CQDs), in view of their excellent physicochemical, sorption, mechanical and electrical properties, find wide application in various areas of human life [1-5]. So, for example, they are used in water purification [6-10], various energy-intensive systems [11, 12], catalyst carriers [13-15], sensors [15-19], targeted delivery of drugs [20-23] and etc. Due to the wide range of applications for carbon nanomaterials, the development of economically viable and environmentally friendly methods for their production remains a topical issue. Traditional technologies for producing carbon nanomaterials most often include energy-intensive stages and use expensive precursors, which, as a result, negatively affects the final cost of the product. In a similar way, the creation or improvement of methods for extracting CNM using available material implies a huge interest from the point of view of industrial orientation, and is also considered the primary problem of many academic and scientific researchers [24-27].

Carbon fiber (CF) is a carbon material with a fibrous (fibrillar) structure with a diameter of no more than 10 μm [28]. According to scientifically proven theoretical data from the International Union of Pure and Applied Chemistry (IUPAC), carbon fibers can be defined as fibers with 92% or more carbon atoms [29]. Carbon fibers can be obtained from various precursors such as: PAN [30-32], lignin [33, 34], rayon [35, 36], polyethylene [37, 38], petroleum and coal tar pitch [39-42].

Due to the nature of the origin and technological methods of processing precursor fibers, various fibers are obtained at the output (Table 1), which mainly differ in mechanical characteristics and mass fraction of the output %. According to [29] CF, they are classified into five types due to their mechanical characteristics:

1. UHM ultra-high modulus type: carbon fibers with a modulus of more than 500 GPa;
2. High modulus class (HM high modulus): carbon fibers with a tensile strength to modulus

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Table 1. Variations of carbon fibers in the base of different progenitor

№	Name	Characteristic
1	PAN based CF	Fibers of different mechanical strength, yield about 50 wt.%
2	CF based isotropic pitches	Fibers mainly with an intermediate modulus of elasticity (general purpose fibers), the yield is more than 75 wt.%
3	CF based on mesophase pitches	Ultra-high modulus fibers, yield more than 75 wt.%
4	Cellulose based CF	Low modulus fibers (general use fibers)
5	Lignin based CF	Low modulus fibers (general use fibers)
6	CF based phenolic resins	Low modulus fibers (general use fibers)

attitude of less than 1% and with an elastic modulus of more than 300 GPa;

3. Class with an intermediate resilient modulus (IM intermediate modulus): carbon fibers with a strength-to-modulus ratio of more than 1×10^{-2} and a resilient modulus up to 300 GPa;

4. Low modulus class (LM low modulus): carbon fibers with modulus of elasticity up to 100 GPa and low strength, these are fibers with an isotropic structure;

5. Class with high tensile strength (HT high tensile strength): carbon fibers with a strength-to-modulus ratio of 1.5 to $2\cdot10^{-2}$ and a tensile strength of more than 3000 MPa.

In this review, we have analyzed the latest achievements in the production and application of CF from oil and coal pitch. The equipment for creating fibers and possible combinations for improving the methods of their extraction are analyzed. Due to the active publication activity in this area of research, this review article includes the results of studies published no later than 2015.

The following chapters provide an overview of recent advances in the production of carbon fibers from petroleum and coal tar pitch using traditional methods, and finally an overview of the wide range of possible applications of these carbon fibers.

2. Obtaining pitch based CFs

Today, carbon fibers can be obtained by the following methods: electrospinning [29, 43-45], melt-spinning [45, 46], catalytic synthesis [47, 48] and vapor deposition [49].

The use of carbon pitches as a cheap and renewable feedstock for CF production is a possible solution to an environmental and economic problem. Resins are a complex mixture of aromatic hydrocarbons, heterocyclic compounds obtained because of distillation of petroleum fractions and coal tar [50, 51].

There are two types of pitches: isotropic and anisotropic (mesophase), which differ from each other in the orientation of the molecules in the structure (Fig. 1). The production of carbon fibers from pitch includes several main stages, which are shown as a diagram in Fig. 2.

Typically, mesophase pitches are considered a premium precursor for high performance carbon materials, including carbon fibers [50], carbon foams [53] and artificial graphite as an anode material [54]. For example, carbon fibers based on mesophase pitch have higher mechanical strength and thermal conductivity in comparison with other carbon fibers, including fibers based on PAN [55, 56]. However, the technological process

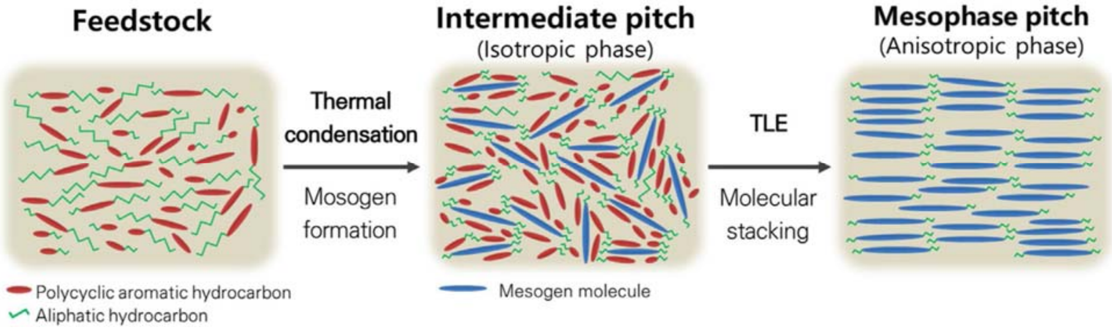

Fig. 1. Diagram of the formation of mesophase pitch, showing the structural differences between isotropic pitch and mesophase [52].

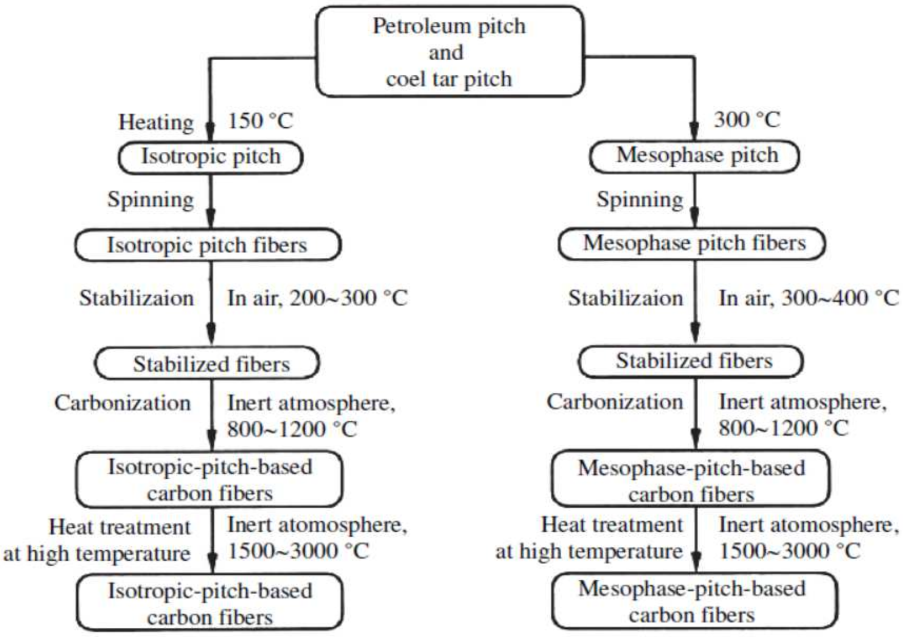

Fig. 2. The main processes in the production of carbon fibers from coal and / or petroleum pitch.

of obtaining mesophase pitch is multistage and energy consuming, which negatively affects the cost of the final product [57].

The properties of the obtained carbon fibers based on pitch are largely determined by the composition of the pitch used, so, for example, to obtain fibers with high mechanical properties, the carbon raw material must be converted from an isotropic phase to an anisotropic phase containing mesophase centers and graphite structures [58]. We have carried out experimental work to obtain composite fibers based on tar with the addition of PAN. As starting materials were used: commercial PAN (DFL Minmet Refractories Corp., China) with the following technical characteristics: purity not less than 99%, density 1.14-1.45 g·cm^{-3}, molecular weight 150.000 g·mol^{-1}, heavy petroleum fractions, as well as an organic solvent N, N-Dimethylformamide (DMF, Sigma-Aldrich ≥99.8%).

To obtain a fiber-forming colloidal solution, a 7% PAN/DMF solution was prepared. Dissolution of PAN was carried out by heating in a 200 cm^3 round-bottom flask equipped with a mechanical stirrer. The dissolution process was carried out with continuous stirring under the influence of a temperature of 80 °C for 6 h. After that, 5 wt.% of tar and stirred for 2 h at 80 °C, followed by ultrasonic treatment at room temperature for 30 min.

The research team set up a fiber electrospinning unit equipped with a drum collector, which makes it possible to increase the efficiency of collection and accumulation of formed fibers on the collector surface. The electrospinning process was carried out as follows: a colloidal solution of PAN/Tar/DMF is fed through a thin nozzle with an internal volume of a syringe of 1 ml, the interelectrode resistance is provided by an electric field in the range of 10-15 kV, and the interelectrode distance is 10-15 cm, the substrate on which the fibers are collected is in contact with the counter electrode and is located in a horizontal position. The diagram of the used installation is shown in the following Fig. 3.

The obtained fiber samples were examined using scanning electron microscopy Fig. 4, as a result of which it can be noted that the fibers have a smooth surface, without surface defects, open porosity and cluster joints, but also despite the fact that the fibers were collected on the surface of the rotating collector, the fibers are located in a random orientation. With this experiment, we wanted to demonstrate the possibility of obtaining composite fibers based on heavy oil fractions, such as tar.

2.1. CFs based on isotropic coal tar pitches

Isotropic pitch carbon fibers are characterized as general-purpose fibers [59]. It is generally assumed that carbon fibers based on isotropic and mesophase pitches are characterized not only by molecular orientation, but also by

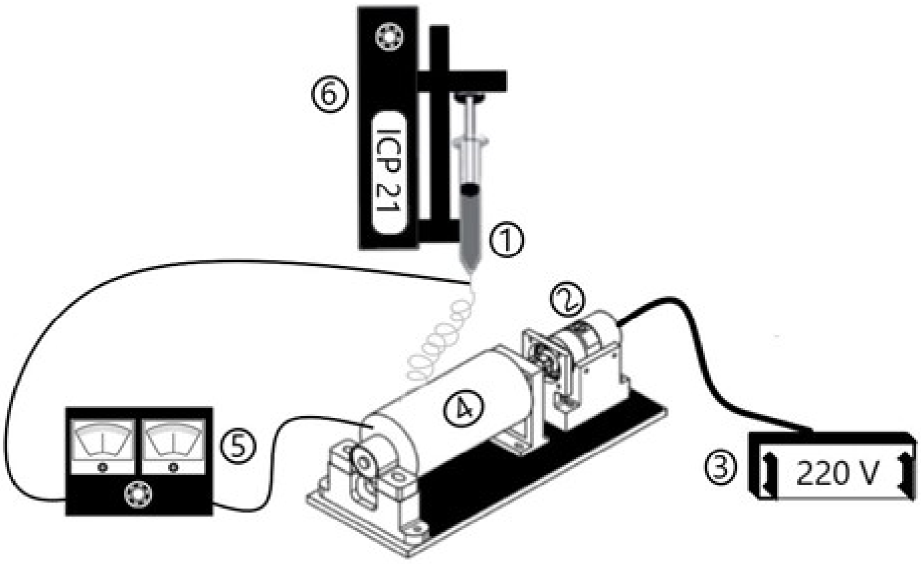

Fig. 3. Diagram of the used installation for electrospinning: 1 – syringe, 2 – motor, 3 – motor speed controller, 4 – drum collector, 5 – high-voltage power supply, 6 – syringe pump.

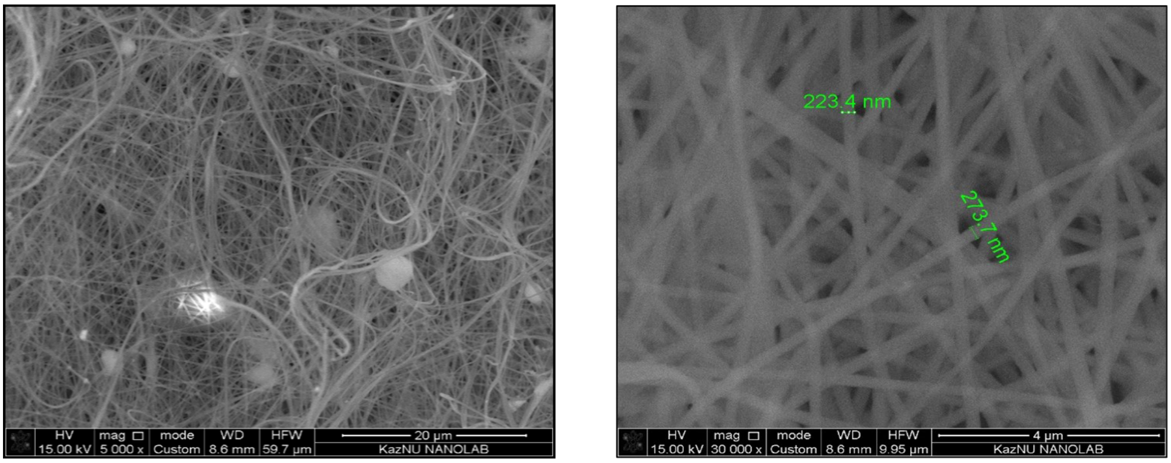

Fig. 4. SEM of PAN/Tar composite fibers.

mechanical parameters [60, 39]. Unlike CFs from mesophase pitches, CFs based on isotropic pitches have random molecular orientation [61]. Nevertheless, to achieve the formation of such mesophase pitches, complex industrial and technical processes are necessary, which further form auxiliary costs and also reduce the potential of CF output for mass production [57]. Based on this, the case of isotropic pitches is of significant economic interest than the CFS of mesophase pitches. In this case, despite the fact that CF based on isotropic pitches have moderate mechanical and galvanic properties, a number of research and experimental works [62, 63] describe the method of their application as components of composite materials with improved mechanical and electrical properties.

Jinchang Liu et al. [59] in their studies describe a method for obtaining CF from an isotropic pitch with moderate mechanical properties and homogeneous morphology of the fiber surface (Fig. 5). This result was achieved by bromination-dehydrobromination of the original pitch.

At the present time, the number of experimental works, in which carbon fibers in the base of isotropic pitches are used in the property of key parts of composite materials used with improved physicochemical and mechanical features, has not become widespread, in contrast to carbon fibers in the base of mesophase pitches. This circumstance is determined by the difference between the physicochemical and automatic data of carbon fibers in the database of various pitches.

Besides, the researchers [64] presented results on the preparation of activated carbon materials, inclusive CFs based on pitches (isotropic). Consequently, activated CFs showed high specific surface areas (~1400 and 900 $m^2 \cdot g^{-1}$). It is noted

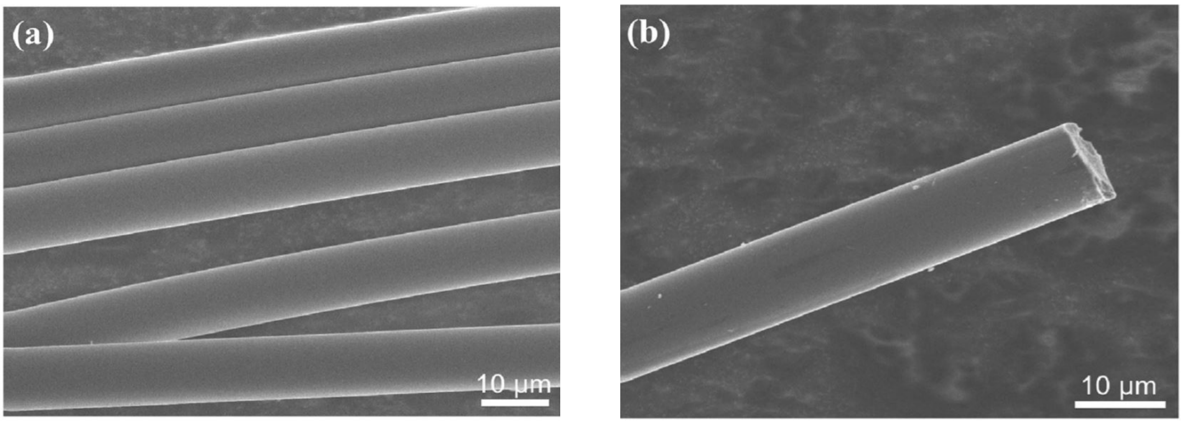

Fig. 5. Surface morphology of carbon fibers observed by SEM: (a) – overall state of ET10CF, (b) – the surface and cross-section of single fiber [59].

that when CFs are activated with CO_2 vapors, the highest specific surface area is observed; however, when activated with ammonia, high functionalization is observed. As a result, high values of the volumetric capacity were achieved, amounting to 124 and 77 $F \cdot cm^{-3}$. In also presenting an overview of research work, it is important to note that research in this direction has great potential for educational purposes, as isotropic resins are considered another economically advantageous precursor for the production of carbon fibers with established features.

2.2. Mesophase coal tar pitch derived CFs

Mesophase pitch, as previously mentioned, has unique physical properties such as high coking properties, low melt viscosity and characteristics of light to low graphitization. Among the types of pitch, this type is a typical nematic liquid crystal formed by a number of aromatic molecules in the form of a disk or rod.

Carbon fibers obtained from mesophase pitch have a highly crystalline nanostructure and differ in tensile modulus of elasticity exceeding 500 GPa and thermal conductivity exceeding 200 $W \cdot (m \cdot K)^{-1}$ [65]. These indicators can be explained by a change in the interlayer distance of less than 0.34 nm, this indicator corresponds to ideal graphite. That is, when the precursor fiber is formed, the liquid crystal pitch molecules are ordered, which leads to this change [66]. It should be noted that carbon fibers obtained from mesophase pitches have a carbon yield of about 75%, from PAN about 45% [67]. Accordingly, CFs based on mesophase pitches have great potential as a high performance carbon fiber precursor. There are various ways to increase the strength of carbon fibers, but the resulting carbon fibers based on masophase pitches have significant potential in increasing their strength while maintaining their electrical conductivity and thermal conductivity, i.e., excellent modules. Possible approaches to increasing the strength of CFs based on mesophase pitches are discussed in the following studies [68], where an approach is described for the production of fiber using an electron beam and stabilization of fibers based on mesophase pitch in an oxidizing environment after spinning and heat treatment conditions for CFs based on mesophase pitches up to 3000 °C [69].

The electron beam enhances the formation of radicals, which provide oxygen to stabilize pitch fibers with more active sites, which showed a higher stabilization index and physical properties of carbon fibers based on mesophase pitch. Carbon fibers exposed to an electron beam have an electrical conductivity of about 600 $S \cdot cm^{-1}$ with a stabilization index (SI) of more than 84%. Consequently, the electron beam significantly reduces the time and energy required to stabilize pitch fibers, and electron beam treated carbon fibers exhibit superior tensile strength and electrical conductivity.

The development of fiber microstructures is directly dependent on melt spinning conditions, that is, improved spinning conditions may lead to further improvements. When improved, the texture in the carbon fibers is retained and determines the properties of the resulting carbon fibers [70].

Guanming Yuan et al. in their research, they obtained carbon fibers based on mesophase pitches using ultrathin spinnerets in the range of capillary diameters of 50-150 μm. According to the results of the study, it was found that a decrease in the size of the die leads to an increase in tensile strength from 1.4±0.2 to 2.3±0.3GPa [71].

Zhai et al. investigated the microcrystalline structure of carbon fibers based on mesophase pitch. The authors estimated the tensile strength of various mesophase carbon fibers with the addition of boron [72].

As a result, it was demonstrated that the degree of graphitization of carbon fibers based on mesophase pitches doped with boron increases due to the catalytic action of boron. The presence of boron leads to a decrease in the distance between layers, an increase in the size of crystallites, and an increase in the preferred orientation of the fibers.

In addition, carbon fibers can be modified by adding various nanofillers such as graphene sheets. Thus, the group of researchers [73] demonstrated that the addition of a small amount of GNS graphene nanosheets (0.1 wt.%) can effectively prevent the formation of radial transverse texture and wedge-shaped splitting in carbon fibers based on mesophase pitch. The authors also argue that this can reduce the complexity and rigidity of spinning the mesophase pitch from the melt. It should be noted that the GNS structure is similar to the graphite structure of planar mesophase molecules, that is, when the GNS addition is small; the defects arising from melt spinning in directly spun fibers can be compensated or improved by subsequent thermo-oxidative stabilization, carbonization and graphitization. Accordingly, GNS/mesophase pitch composite carbon fibers have high mechanical strength and high conductivity. It should be noted that at present, the amount of patent and technical literature devoted to the production of carbon fibers from pitches has increased dramatically and, perhaps, it would not be an exaggeration to say that this topic ranks first in comparison with other methods of producing carbon fibers. First of all, this concerns the production of high-modulus carbon fibers from mesophase pitch.

3. Application of pitch derives CFs

According to [74] pitch-based carbon fibers can be divided into two classes: general CF (derived from isotropic pitch) and high (derived from anisotropic and mesophase pitch) productivity. Uniform properties carbon fibers reveal their own use in similar areas, as well as water purification, adsorption also in the property of the thermal insulation material used. Contrastingly, carbon fibers of considerable productivity due to their good electrical conductivity are used in the anode property for the purpose of supercapacitors, storage of various types of gases, which is confined to several experimental works. Defined with the key actual use of carbon fibers in the database, the annoyances discussed are also described below.

3.1. Energy storage systems

Today, renewable energy sources, as well as alternative energy resources, are a topical trend all over the world. At the same time, energy storage systems such as various batteries [75], fuel cells [76] and electrochemical capacitors [77] (supercapacitors) are evolving and are increasingly referred to as next generation technologies that will help overcome the world's energy crisis. Supercapacitors are special types of capacitors that have a high electron transfer rate, which facilitates fast charging, and are characterized as devices with a long life cycle and low maintenance costs.

One of the main differences between conventional capacitors and supercapacitors is the capacitance density, which directly depends on the amount of charges that can be stored per unit mass of the active substance. Typically, the capacitance of a supercapacitor is two or three orders of magnitude greater than that of a conventional capacitor [78]. Such high performance is achieved because, unlike conventional capacitors, supercapacitors use electrodes based on porous materials with a high specific surface area. One of these materials is carbon fiber, most often activated or modified with various additives.

Dan Yue et al. demonstrate the possibility of obtaining carbon fibers based on pitches from ethylene resin with various additions of polyethyleneimine (from 0 to 30 wt.%) using the extrusion method, with further stabilization, carbonization and activation of the fibers. Nitrogen was doped into the activated carbon fibers, after which the resulting fibers were investigated by various physicochemical methods of analysis, and as a result, it was found that activated carbon fibers with doped nitrogen have higher specific surface area (2756 m^2) and capacity (314 $F \cdot g^{-1}$ at 0.5 $A \cdot g^{-1}$), while the untreated activated carbon fibers have a capacity of 194 $F \cdot g^{-1}$. In the production of carbon fibers with improved electrochemical characteristics, it is important not only what method of processing or modification is used, but also what method the precursor fibers were obtained [79]. Thus, Yun Zheng et al. demonstrated a method for producing carbon fibers by centrifuged electrospinning. As a result, it was found that the use of this method improves the electrochemical and mechanical properties of the resulting fibers, in contrast to traditional electrospinning. The resulting fibers are characterized by the presence of micro-, meso- and macropores, which directly affect the maximum capacity, which was 277 $F \cdot g^{-1}$ at a density of 0.2 $A \cdot g^{-1}$ [80].

Researchers [81] was found that pitch-based carbon fibers in the PAN/carbon nanofiber/MnO_2 (PPMn-CNF) composite facilitate the access of electrolyte ions into micropores and have a positive effect on the efficiency of their adsorption on the electrode surface in aqueous electrolytes. For a more detailed comparison, an analysis of the literature was carried out to establish the maximum and minimum indicators of the specific capacity and energy density of various composites based on carbon fibers, which were used as an electrode for supercapacitors (Table 2).

These and many other works show tremendous promise for pitch-based carbon fibers for use in energy storage with high capacity and high energy density.

3.2. Carbon-fiber-reinforcement based on pitches

Carbon fiber reinforced polymers (CFRP) are the foremost vital composite material. They are utilized within the flying industry, but due to the diverse coefficient of warm extension (KTR) of the constituent components, noteworthy remaining stresses may happen at the interface. Remaining stresses influence the physical and mechanical characteristics of composite materials and can cause dimensional precariousness, harm advancement and untimely annihilation.

Thus Lang F. et al. propose to remove residual stresses by combining the method of cracks in the matrix with the method of geometric phase analysis (GPA). Residual stress affects the physical and mechanical characteristics of composite materials and can cause dimensional instability, damage development and premature destruction. According to the results of the experiment, the average value of the interfacial radial residual voltage in the fiber layer at an angle of 90° was -6.7±1.3 MPa, which is less than 7% lower than the theoretical value (-7.2 MPa). This shows that this method is feasible for improving the characteristics of reinforced carbon fibers and their further promising application in the aviation industry [85].

N. Mahaviradhan et al. an experimental study of the mechanical properties of a composite material with an aluminum AA6061 metal matrix reinforced with carbon fiber based on pitch was carried out. The experimental work consists of several systematic stages, which are demonstrated in the following fig. In operation, the mass percentage of carbon fiber varies from 0 to 10%.

Research has shown that the hardness of 6061 aluminum alloy and pitch-based carbon fiber composites increased with increasing addition of carbon fiber. Tensile strength finally improved with increasing carbon fiber content, while ductility and brittleness decreased. The addition of pitch-based carbon fiber mesh layers resulted in a significant increase in toughness [86].

On the other hand, Risheng Pei et al. found that reinforced aluminum composites (P100/1199, P100/6063, P120/1199 and P120/6063 (Fig. 6)) with the addition of carbon fibers significantly improved the thermomechanical properties (Fig. 7) of these composites [87], which are superior to those demonstrated in a similar study [86]. Mesophase pitch carbon fiber (MPCF) exhibits ultra-high thermal conductivity and low axial thermal expansion, as well as high machinability, providing excellent unidirectional heat dissipation performance, and meeting special heat sink requirements. Therefore, the values of high thermal conductivity, low coefficient of thermal expansion, metal matrix composites reinforced with MPCF are promising for use in electrical equipment, electronic packaging materials and other areas.

Table 2. Comparison of the characteristics of different composites in the carbon fiber base for the purpose of application in the electrode property for the purpose of supercapacitors

Year	Material	Specific capacity	Energy density	Reference
2020	Resin based on activated carbon fiber	314 $F \cdot g^{-1}$	0.5 $A \cdot g^{-1}$	[79]
2020	Porous carbon fibers based on nitrogen doped asphaltenes	301-482 $F \cdot g^{-1}$	1.0 $A \cdot g^{-1}$	[82]
2017	Pitch-based activated carbon fibers	22.5 $F \cdot g^{-1}$	0.5 $A \cdot g^{-1}$	[83]
2019	Lignin/pitch carbon nanofibers with added ZnO	165 $F \cdot g\text{-}1^{1}$	22 $W \cdot h \cdot kg^{-1}$	[84]
2015	Pitch-based activated carbon fibers	90 $F \cdot g^{-1}$	0.5 $A \cdot g^{-1}$	[64]

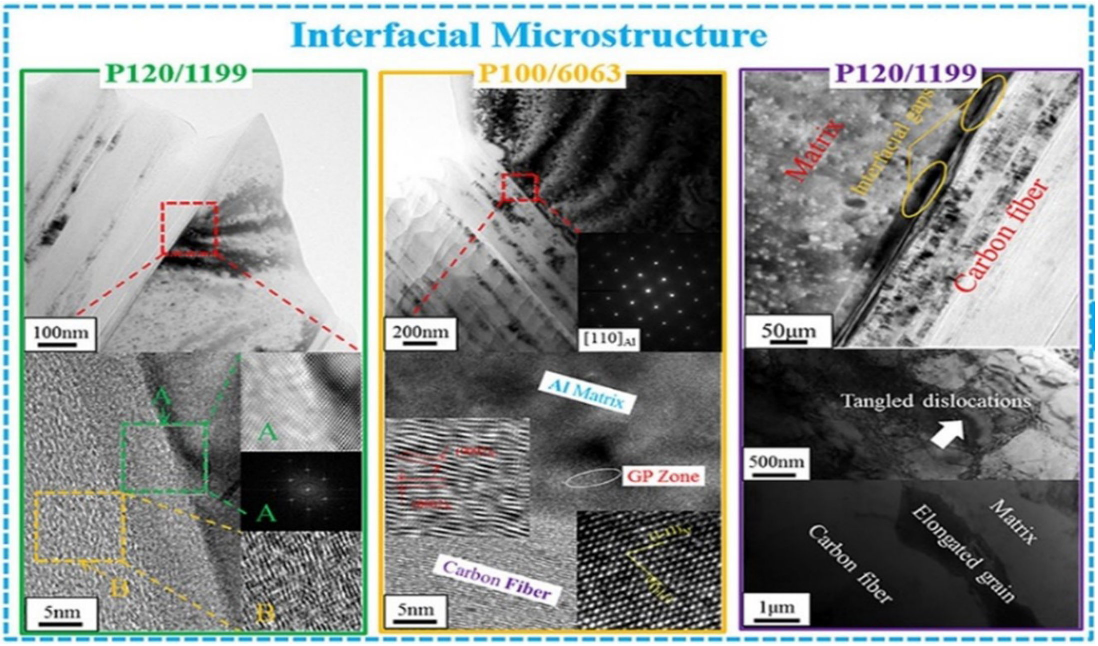

Fig. 6. Morphology of the interface between carbon fiber and a matrix of pure Al in composites [87].

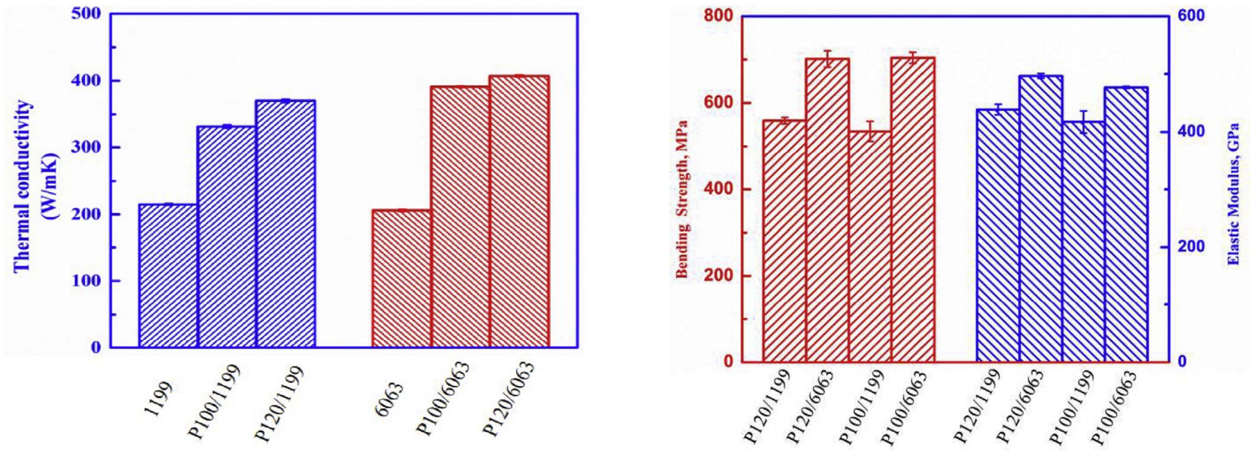

Fig. 7. Thermal conductivities (a) and Elastic modulus with bending strength (b) of the different composites and matrix [87].

As a result, a composite was gotten with medium warm conductivity, coefficient of warm extension and tall modulus of versatility; in differentiate to other composites with an aluminum network and aluminum amalgams. In this association, we seem say that the utilize of pitch-based carbon filaments has incredible prospects for getting composites within the shape of heat-conducting and mechanically solid added substances. Although carbon filaments based on mesophase pitches have tall quality characteristics and a moo coefficient of warm development, the most elevated esteem of warm conductivity has not been accomplished, this making it vital to carry out a more exhaustive examination of this heading. It is accepted that by utilizing carbon filaments with a tall coefficient of warm expansion, it is conceivable to extend the warm conductivity.

4. Conclusion

Most of the conventional strategies for creating carbon nanomaterials are based on the utilize of costly antecedents, which is the most restriction of their large-scale application. The use of coal tar or petroleum tar, which is an inexpensive precursor to produce various kinds of carbon nanomaterials, will make it possible to use them not only for sustainable production and storage of energy, but also for the creation of new composite materials with high thermomechanical properties. Present day strategies for getting CNF are pointed at moving forward the morphology, stabilization, and enactment parameters to make strides their physical and chemical characteristics. Despite active research in this area, there are a number of problems, first of all, this is the high final cost of carbon fibers when using mesophase pitches due to the high cost of the processes of converting isotropic pitches into mesophase ones, and secondly, the resulting pitches often contain various pollutants, such minor components as sulfur, which ultimately can significantly affect the morphology and electrical conductivity of the resulting carbon fibers, it is also worth noting the loss of mass of the active substance after high-temperature treatments (graphitization, activation), which can reach up to 60-70% of the total mass. The key errands for tackling these issues are the adjustment of advanced strategies for getting CNF to make a complex controlled permeable structure with made strides dynamic centers, as well as the creation of heterostructures based on CNF. Changing the structure of pitch-based carbon filaments by making multicomponent heterostructures can successfully influence the weight misfortune amid actuation and graphitization, as well as increment the separate between layers. The examination of the writing has appeared that CNFs can be successfully utilized in different applications and have great potential for commercializing low-cost items within the worldwide economy. The possibility of obtaining composite fibers based on tar was also demonstrated, which has a prospect in this direction and a more thorough study with this material should be carried out.

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Углеродные волокна на основе пека: приготовление и применение

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Аннотация

Интерес к углеродным волокнам (УВ) обусловлен их уникальными физико-химическими, механическими и электрическими свойствами, что делает их востребованными в различных сферах деятельности. На сегодняшний день существует несколько типов углеродных волокон, большинство из которых (около 90%) производятся из полиакрилонитрила (ПАН). Несмотря на то, что углеродные волокна производятся из нескольких видов различных прекурсоров – их широкое коммерческое применение ограничено высокой себестоимостью продукта. В связи с этим многие исследовательские и инженерные группы ставят перед собой цель достичь более низкой себестоимости продукта за счет использования дешевых типов углеродного сырья. Возможным решением данной проблемы является использование угля, нефтяной и каменноугольной смол в качестве эффективного прекурсора для получения УВ. В работе рассматривается недавний прогресс в синтезе УВ с использованием различных углеродных пеков. Представлена возможность получения углеродных волокон на основе гудрона с добавлением ПАН, а также подробно описаны перспективы их применения в системах хранения энергии и различных армированных композиционных материалах.

Ключевые слова: углеродные волокна, каменноугольный пек, нефтяной пек, мезофазные пеки, изотропные пеки, наноматериалы

Пек негізіндегі көміртекті талшықтар: дайындау және қолдану

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Аңдатпа

Көміртекті талшықтарға (КТ) қызығушылық олардың ерекше физика-химиялық, механикалық және электрлік қасиеттеріне байланысты, бұл оларды әртүрлі қызмет салаларында сұранысқа ие етеді. Бүгінгі таңда көміртегі талшықтарының бірнеше түрлері белгілі, олардың көпшілігі (шамамен 90%) полиакрилонитрилден (ПАН) жасалған. Көміртекті талшықтар әртүрлі прекурсорлардың бірнеше түрінен жасалғанына қарамастан – оларды кеңінен коммерциялық қолдану өнімнің жоғары өзіндік құнымен шектеледі. Осыған байланысты көптеген ғылыми – зерттеу және инженерлік топтар арзан көміртекті шикізатты пайдалану арқылы өнімнің өзіндік құнын төмендетуге ұмтылады. КТ өндірісі кезінде тиімді прекурсор ретінде көмірді, мұнай мен көмір шайырын қолдану мәселенің ықтимал шешімі болып табылады. Бұл мақалада, әр түрлі көміртегі пектерін қолдана отырып, КТ синтезіндегі соңғы прогресс қарастырылады. Сонымен қатар, ПАН қосылған гудрон негізіндегі көміртекті талшықтарды алу мүмкіндігі ұсынылған және оларды энергия сақтау жүйелерінде және әртүрлі арматураланған композициялық материалдарда қолдану болашақтағы перспективы егжей-тегжейлі сипатталған.

Кілт сөздер: көміртекті талшықтар, көміртекті пек, мұнай пекі, мезофазалық пек, изотропты пек, наноматериалдар.