Discussion on The Preparation Technology and Practical Application of Mesophase Pitch-Based Carbon Fiber

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Abstract: This article focuses on the preparation and application of mesophase pitch-based carbon fibers. Starting from the characteristics of raw materials, the influence of coal tar pitch and petroleum pitch on the formation of mesophase is discussed, and the preparation methods and key parameters of thermal polymerization and catalytic polymerization are introduced. Comparative process optimization of melt spinning and solution spinning in the spinning process. Parameter control during the stabilization and carbonization processes is crucial to the performance of carbon fibers. In terms of practical applications, this material has demonstrated significant advantages in weight reduction, energy improvement, and durability in the fields of aerospace, automobiles, sports, wind power, and construction, making it the new favorite of high-performance materials.

Keywords: Mesophase Pitch-Based Carbon Fiber; Preparation Process

1. Introduction

Carbon fiber, a leader in high-performance fiber materials, has occupied an important position in modern industry and high-tech fields with its excellent high strength, high modulus, low density and excellent high temperature resistance. From aerospace to national defense and military, from high-end sports equipment to new energy vehicles, carbon fiber is everywhere, demonstrating its great contribution to scientific and technological progress and industrial upgrading. As a shining pearl in the carbon fiber family, mesophase pitch-based carbon fiber is increasingly becoming the focus of scientific research and industry due to its unique microstructure and excellent performance. In-depth exploration of the exquisiteness of its preparation process and tapping its practical application potential in various fields is not only crucial to promoting the continuous progress of carbon fiber technology, but also will inject new vitality and kinetic energy into the vigorous development of related industries.

2. Preparation Process of Mesophase Pitch-Based Carbon Fiber

2.1 Raw Material Selection

The raw materials for preparing mesophase pitch mainly include coal tar pitch, petroleum asphalt, etc. Coal tar pitch has the advantages of high aromaticity and high carbon content, and is one of the commonly used raw materials. The composition of coal tar pitch from different origins and processing techniques varies. Its quinoline insoluble content, softening point and other indicators have an important influence on the subsequent formation of mesophase pitch. For example, the quinoline insoluble content of coal tar pitch is generally required to be within a certain range. Too high a content will affect the growth and fusion of the mesophase, while too low a content may make it difficult to form the mesophase. Petroleum asphalt has the characteristics of low cost and wide sources. The proportion of saturated components, aromatic components, colloids and asphaltene in its composition needs to be reasonably controlled.

2.2 Preparation of Mesophase Pitch

Thermal polymerization is one of the common methods for preparing mesophase pitch. The raw asphalt is heated to a certain temperature under an inert atmosphere, generally between 350 and 450°C. In this process, the small molecular aromatics in the asphalt gradually form large molecular polycyclic aromatics through condensation reaction, and then form the mesophase. For example, when coal tar pitch is thermally polymerized at 400°C for a certain period of time, the mesophase content will increase with time, but when the time is too long, the mesophase may grow excessively and agglomerate. Through experimental research, it was found that by thermal polymerization at 400℃ for 6-8 hours, a better mesophase pitch can be obtained, which has obvious optical anisotropy and the mesophase content can reach about 80%.

2.3 Spinning

Melt spinning is to heat the mesophase pitch to above its melting point and extrude it through a spinneret to form fibers. The melting point and viscosity of the mesophase pitch are key factors affecting melt spinning. Generally speaking, the appropriate spinning temperature range is 280-350℃. For example, when the spinning temperature is 320℃, the spinning stability and fiber uniformity are better. In the melt spinning process, parameters such as the spinneret aperture and aspect ratio also have an important influence on the fiber diameter and quality. Usually, the spinneret aperture is between 0.2-0.5mm and the aspect ratio is between 2-4, which can obtain fibers with uniform diameter and smooth surface.

3. Technical Points and Analysis of Influencing Factors in The Preparation Process

3.1 Control of Mesophase Structure

The structure and quality of the mesophase directly affect the performance of the carbon fiber. In the preparation process of mesophase pitch, the polymerization reaction conditions, such as temperature, time and catalyst dosage, should be precisely controlled to obtain a suitable mesophase structure. A good mesophase structure should have a high degree of orientation and uniformity. For example, X-ray diffraction (XRD) analysis found that when the mesophase pitch has a good orientation structure, it exhibits a higher modulus in the subsequently prepared carbon fiber. At the same time, the content of the mesophase also needs to be controlled within an appropriate range. Too high or too low will affect the performance of spinning and carbon fiber.

3.2 Optimization of Spinning Process Parameters

During the spinning process, the diameter, surface quality and internal structure of the fiber are crucial to the performance of the carbon fiber. During melt spinning, a slight change in temperature may cause a significant change in the viscosity of the pitch, thereby affecting the diameter uniformity of the fiber. During solution spinning, the choice of solvent and the concentration of the solution not only affect the feasibility of spinning, but also affect the microstructure of the fiber. For example, scanning electron microscopy (SEM) observations found that when the solution concentration is too high or too low, defects such as holes and cracks will appear on the fiber surface. These defects will further expand during the subsequent stabilization and carbonization process, reducing the strength of the carbon fiber.

3.3 Effect of Stabilization and Carbonization Conditions

Insufficient oxidation during the stabilization process will cause the fiber to melt and stick during the carbonization process, while excessive oxidation will reduce the strength of the fiber. The control of carbonization temperature and time has an important influence on the crystallinity and graphitization degree of carbon fiber. Through Raman spectroscopy analysis, it can be found that with the increase of carbonization temperature, the graphitization degree of carbon fiber increases, and the intensity ratio of its D peak to G peak changes. For example, the graphitization degree of carbon fiber carbonized at 2800℃ is significantly higher than that of carbon fiber carbonized at 2000℃, showing higher modulus and conductivity.

4. Practical Applications of Mesophase Pitch-Based Carbon Fibers

4.1 Aerospace Field

4.1.1 Aircraft Structural Parts

In the aviation field, mesophase pitch-based carbon fiber is gradually becoming the preferred material for aircraft structural parts due to its unique advantages of light weight, high strength and high modulus. Compared with traditional metal materials, the density of mesophase pitch-based carbon fiber is only about 1/3 of aluminum alloy, but its strength is much higher than that of aluminum alloy, which makes it play a vital role in reducing the weight of aircraft structures. . Taking the design of a new fighter jet wing as an example, after using mesophase pitch-based carbon fiber composite materials, the weight of the wing has been significantly reduced by about 30%, while fully meeting the stringent design requirements in terms of strength and stiffness. This change not only improves the fuel efficiency of the aircraft, but also greatly enhances its flight performance, opening up a new path for the green development of the aviation industry.

4.1.2 Spacecraft Components

In the aerospace field, the high temperature resistance and radiation resistance of mesophase pitch-based carbon fibers are particularly important. Spacecraft need to withstand extreme high temperatures, radiation and other harsh conditions in the space environment, and mesophase pitch-based carbon fiber composites are ideal for meeting these challenges. Among key components such as satellite solar panel brackets and antenna reflectors, its stable performance is particularly outstanding. Experimental data simulating the space environment shows that after severe tests of high temperature and radiation, the performance retention rate of mesophase pitch-based carbon fiber composites is as high as over 90%, far exceeding that of other traditional materials, providing a strong guarantee for the long-term stable operation of spacecraft. .

4.2 Automobile Industry

4.2.1 Body Frame

In the modern automobile manufacturing industry that pursues lightweight and high performance, mesophase pitch-based carbon fiber is gradually becoming the leader in body frame materials. Its lightweight and high-strength characteristics allow cars using carbon fiber body frames to significantly reduce weight. Compared with traditional steel bodies, the weight reduction can reach more than 50%. This significant change not only directly improves the vehicle's acceleration performance and fuel economy, but also indirectly reduces emissions, in line with the future trend of green travel. More importantly, the high-strength properties of carbon fiber ensure the body's excellent safety in the event of a collision. Crash test data shows that the carbon fiber body can effectively absorb and disperse impact energy when it is hit, thereby greatly reducing the risk of injury to people in the car and providing a more solid protective barrier for drivers and passengers.

4.2.2 Engine Parts

In the engine, the heart of the car, mesophase pitch-based carbon fiber also shows extraordinary application potential. Especially in key locations such as high-temperature components such as turbine blades and intake manifolds, the high-temperature resistance of carbon fiber is particularly important. Compared with traditional metal materials, carbon fiber turbine blades can maintain better strength and stiffness in high temperature environments, effectively improving the efficiency and reliability of the engine. In addition, the application of carbon fiber materials can also help reduce the thermal expansion coefficient of engine components and reduce dimensional changes caused by temperature changes, thus extending the service life of the engine and injecting new vitality into the technological innovation and performance improvement of the automotive industry.

4.3 Sporting Goods

In the field of tennis rackets, the application of mesophase pitch-based carbon fiber also brings significant performance improvements. Its perfect combination of high strength and low weight gives the tennis racket faster swing speed and stronger hitting power. Actual test results from athletes show that after using carbon fiber tennis rackets, the serve speed is increased by 5% to 10% on average, which means players can more easily serve high-speed balls and take advantage of the game. In addition, the carbon fiber tennis racket feels better when hitting the ball. Players can more accurately perceive the contact point between the racket and the ball, thereby more accurately controlling the direction and rotation of the ball, improving the competitive level and enjoyment of the game. The application of carbon fiber materials has undoubtedly injected new vitality and possibilities into tennis.

5. Conclusion

The preparation process of mesophase pitch-based carbon fiber is complex, and the parameters of each link need to be precisely controlled to ensure performance. It is widely used in aerospace, automobile, sports and other fields, showing excellent performance and becoming the preferred alternative to traditional materials. With process improvement and cost reduction, the application prospects are broad. Future research should focus on process optimization, performance improvement and expansion of new fields.

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