Structural evolution of rubber-wood char under different pyrolysis conditions

Liang Liu1,2, Ya Cao1,2, Mengxia Qing1,2* and Yutian Long1,2

1College of Energy and Power Engineering, Changsha University of Science and Technology, Changsha, Hunan, 410114, China
2Hunan Key Laboratory of Renewable Energy Power Technology, Changsha University of Science and Technology, Changsha, Hunan, 410114, China
*Corresponding author’s e-mail: qingmx@csust.edu.cn

Abstract. In order to explore the effect of different pyrolysis conditions on the structural characteristics of rubber wood biomass pyrolysis, rubber wood char was prepared under fast pyrolysis and slow pyrolysis conditions. The char was analyzed by BET, SEM, FT-IR and Raman spectroscopy to explore the effects of different pyrolysis conditions on pore characteristics, surface structure and chemical structure. The results showed that the nitrogen isothermal adsorption/desorption curves of slow pyrolysis at 900℃ are obviously different, and the char structure has a certain amount of mesopores and macropores. With the pyrolysis temperature increased, the alkane side chain of rubber wood char broke, and formed a large number of active sites, which promoted the condensation of small aromatic rings into large aromatic ring structures, and deepened the aromatization of char structures. The rapid pyrolysis method causes the content of the small aromatic ring structure to be greater than that of the large aromatic ring structure at a lower temperature contrarily.

1. Introduction

With the increasingly tense energy situation in China, the renewable energy development and utilization are growing year by year. As a new type of energy, biomass has abundant energy reserves and extensive resources. It is the fourth largest energy source besides coal, oil, and natural gas. Biomass pyrolysis technology is one of the effective technical means to convert low energy density biomass resources into high energy density gas, liquid, and solid products[1]. In the thermochemical conversion of biomass, the pyrolysis is the key initial stage. The parameters of the pyrolysis process have a significant impact on the semi-tar, oil and pyrolysis gas after the pyrolysis reaction of biomass.

Biomass pyrolysis semi-coke is of developed pore structure and good reactivity. Scholars at home and abroad have done a lot of research on the influence of different pyrolysis parameters on the formation process of biomass semi-coke. How pyrolysis temperature, heating rate, pyrolysis atmosphere and pyrolysis time influenced on the structure of semi-coke was focused. Liu[2] performed a pyrolysis experiment on corn stalks to explore the effect of pyrolysis temperature on the physical and chemical properties of biomass char. They found that as the pyrolysis temperature increases, the H/C and O/C molar ratios gradually decrease. The specific surface area was generally low, in the range of 3.8-4.4m2/g, and the surface change of biomass char was not obvious. Chang[3] used wheat straw as the raw material, and found that the chemical bond of the straw was broken during the pyrolysis process and the
disappearance of the fatty alkyl chain. With the increase of temperature, the polarity of biochar decreases, the aromaticity increases, the hydrophobicity increases, the pore wall became thinner and the internal structure gradually increased. Lin[4] found the rice husk charcoal prepared at a temperature of 550-650°C was of high soluble matter and developed pore structure characteristics. Chen[5] measured the pore distribution characteristics of pyrolysis char with a specific surface area pore size analyzer. With the increase of the final pyrolysis temperature, the pore structure of biomass char became complicated. It was of better characteristics at 600°C, and pore collapsed and fused at 1000°C. Chammeddeine[6] found that when the temperature was beyond 800°C, the surface chemical properties of the surface functional groups became worse; and as the temperature rised, the order of the carbonaceous structure increased, and the amorphous structure disappeared. Mustapha[7] Slowly pyrolyze the two kinds of biomass, and found their pores are mainly macropores with a size of 2-7μm. Yin[8] pyrolyzed pine needles and corn stalks at different temperatures. As the temperature increased, the content of carbon, hydrogen, and oxygen functional groups in biochar decreased, which improved the structure of aromatic macromolecules at high temperatures. Liu[9] found that pyrolysis at different temperatures, there was no significant difference in nitrogen and sulfur content. And there was less aliphatic on the surface of biochar at higher temperatures. Fu[10] conducted pyrolysis experiments on corn stalks and found that as the temperature increased, the aromatization of char deepened and the carbon content increased significantly; while the hydroxyl, carbonyl and alkene gradually disappeared.

As a typical tropical economic plant, rubber wood has a large output and a wide range of uses. Therefore, the pyrolysis technology of rubber wood has considerable application prospects. However, there are few studies on the pyrolysis characteristics of rubber wood; especially the influence of pyrolysis process parameters on the char structure during the pyrolysis process of rubber wood was relatively scarce. Based on this, this paper takes rubber wood as the research object, prepares for rubber wood pyrolysis semi-coke under different pyrolysis conditions, and characterizes its pore characteristics, surface morphology, surface chemical properties and chemical structure; And explores the influence of different conditions on the physical and chemical properties of the char structure and the evolution law, which provide a certain theoretical and reference basis for the thermochemical conversion and utilization of rubber wood.

2. Material and Methods

2.1. Sample preparation

The rubber wood selected for the experiment was from Hainan Province, China. The rubber wood is washed to remove surface adhesions and sent to a blast drying box to remove surface moisture. Then the rubber wood is crushed in the crusher to particles smaller than 105 μm, and then dried in a blast drying box at 105°C for 24 hours.

The rubber wood char in the experiment was prepared in a horizontal tube furnace. This experiment uses two pyrolysis methods, namely fast pyrolysis and slow pyrolysis. Under slow pyrolysis conditions, the rubber wood was placed in a porcelain boat and pushed into the central heating zone of the tube furnace, and nitrogen with a purity of 99.99% is continuously injected for 10 minutes to remove the remaining air in the tube. Then adjust the controller of the horizontal tube furnace to heat to the final temperature at a heating rate of 10°C/min, and a nitrogen flow rate of 800 mL/min. The rubber wood char was prepared under slow pyrolysis conditions is named MS-XX. Under the conditions of rapid pyrolysis, the horizontal tube furnace is first raised to the final temperature and kept at a constant temperature, and the rubber wood was quickly pushed to the central heating area of the horizontal tube furnace for 30 minutes. The rubber wood char prepared under fast pyrolysis conditions is named KS-XX. For example, KS-800-30s means rubber wood char prepared by rapid pyrolysis at 800°C with a residence time of 30s. The ultimate analysis of rubber wood and char were shown in Table 1.
Table 1. Ultimate analysis of rubber wood and char.

| Sample        | C(%) | H(%) | O*(%) | N(%) | S(%) | H/C   | O/C   |
|---------------|------|------|-------|------|------|-------|-------|
| rubber wood   | 37.15| 6.32 | 56.67 | 1.29 | 0.57 | 0.170 | 1.525 |
| MS-300        | 65.99| 4.41 | 28.67 | 0.51 | 0.42 | 0.066 | 0.434 |
| MS-400        | 71.89| 3.71 | 23.52 | 0.53 | 0.35 | 0.051 | 0.327 |
| MS-500        | 78.77| 1.47 | 19.07 | 0.34 | 0.35 | 0.039 | 0.242 |
| MS-600        | 79.05| 3.14 | 16.93 | 0.54 | 0.34 | 0.030 | 0.214 |
| MS-700        | 80.71| 1.60 | 16.93 | 0.42 | 0.34 | 0.022 | 0.209 |
| MS-800        | 81.28| 1.84 | 16.11 | 0.40 | 0.38 | 0.019 | 0.198 |
| MS-900        | 82.28| 2.51 | 14.39 | 0.48 | 0.34 | 0.018 | 0.174 |
| KS800-30s     | 76.86| 2.74 | 19.44 | 0.70 | 0.26 | 0.035 | 0.252 |
| KS800-60s     | 77.95| 1.99 | 19.14 | 0.68 | 0.25 | 0.028 | 0.245 |
| KS800-120s    | 78.45| 1.74 | 18.80 | 0.81 | 0.20 | 0.025 | 0.239 |
| KS800-240s    | 78.54| 2.24 | 18.40 | 0.61 | 0.22 | 0.022 | 0.234 |
| KS400-30min   | 70.21| 3.75 | 25.22 | 0.72 | 0.1  | 0.053 | 0.359 |
| KS600-30min   | 76.54| 1.49 | 21.20 | 0.58 | 0.18 | 0.032 | 0.277 |
| KS800-30min   | 78.73| 2.54 | 17.95 | 0.63 | 0.15 | 0.019 | 0.228 |

2.2. Characterization of rubber wood and char

2.2.1. Physical characterization. The pore characteristics and specific surface area are measured by nitrogen low-temperature adsorption experiment using a specific surface area tester (Micromeritics ASAP 2020M), and the specific surface area is measured by a multi-point Brunauer-Emmett-Teller (BET) model calculation, micropore volume and total pore volume are calculated by Dubinin-Radushkevich (DR) model, and the average pore diameter is calculated by Dubinin-Astakhov (DA) model. Before the sample test, first carry out 5h degassing treatment at 350°C. The microscopic surface morphology of rubber wood was tested with a scanning electron microscope (SEM) on the Sigma 3000 electron microscope of ZEISS. Before the test, the sample was sprayed with gold at an accelerating voltage of 2.0KV. After pretreatment, the biochar samples were imaged with an energy scattering spectrometer.

2.2.2. Chemical characterization. The composition of functional groups on the surface of rubber wood char was measured by Thermo Fisher Nicolet IS 50 Fourier Transform Spectrometer (USA). Mix the sample with KBr at a ratio of 1:50 and grind it into a fine powder in an agate mortar, then press the mixed powder into a tablet for FT-IR spectroscopy. The number of scans for each sample is 32 times, at 400-4000cm⁻¹. The spectrum is collected within the range, the resolution is 4cm⁻¹, and the test temperature is 25°C. The Raman spectroscopy test was performed on rubber wood and its char samples, using Jobin Yvon Lab RAM HR800 micro-confocal Raman spectrometer to test, using Nd-YAG laser, wavelength λ₀=532nm, laser power 5mW. Raman spectra are collected in the range of 500-3500cm⁻¹.

3. Results and discussions

3.1. Sample analysis

Due to the incomplete carbonization of organic matter during the pyrolysis process, it contains not only incompletely carbonized organic carbon, but also highly carbonized organic carbon from Table 1. As the preparation temperature increased, biochar gradually converted from rubbery carbon to glassy carbon [11]. As the temperature of slow pyrolysis increased, the carbon content of biochar increased from 65.99% to 82.28%, and the oxygen content of biochar decreased from 28.67% to 14.39%. Under
high temperature conditions, a large amount of oxygen in biomass is consumed; therefore the oxygen content of biochar decreased with the temperature increased. Similarly, rapid pyrolysis can also cause that the carbon content in biochar gradually increased with temperature and residence time increased. In addition, the oxygen content of biochar in fast pyrolysis also increases with the increase of temperature and residence time, which showed as the same decreasing law as slow pyrolysis. Comparing the char samples prepared under slow and fast pyrolysis conditions, it can be found that H/C gradually decreases with the increase of pyrolysis temperature, indicating that under high temperature conditions, it is beneficial to the carbonization and aromatization of biomass materials. And the increased temperature decreases the polarity of biochar. Biochar has gradually converted from rubbery state to glassy state[12]. The index of O/C gradually decreases with the increase of temperature and residence time, indicating that the hydrophobicity of biochar is gradually increasing.

3.2. Pore structure analysis

During the pyrolysis process, the pore structure of rubber wood semi-coke will change greatly. The effect of pyrolysis conditions on the pore structure characteristics, pore size distribution and specific surface area distribution of rubber wood semi-coke was investigated by nitrogen isothermal adsorption/desorption method. The nitrogen isotherm adsorption/desorption curves of rubber wood semi-coke prepared at different final pyrolysis temperatures during slow pyrolysis was shown in Figure 1. From Figure 1(a) and (b), the isothermal adsorption/desorption curves of rubber wood semi-coke nitrogen with the final temperature range of 300℃ to 800℃ basically coincide with a little difference. By BDDT classification method, the curve is a typical type III isotherm. When the relative pressure (P/P0) is less than 0.2, the slopes of the adsorption isotherms of the six semi-cokes are small. The adsorption amount rises slowly with the increase of pressure, indicating that the force between nitrogen adsorbate and semi-coke solid surface is weak. In the middle relative pressure section, the adsorption capacity rises rapidly with the increase of pressure, which means the formation of a monolayer of nitrogen adsorbate and the conversion to multiple layers. In the high relative pressure section, the adsorption capacity increases rapidly, indicating that there are a certain number of mesoporous and macroporous structures in the semi-coke particles. The hysteresis loop formed by the desorption curve and the adsorption curve does not belong to the five standard hysteresis loops provided by de Boer, indicating that the pores inside the six semi-focuses are multi-morphic and are the superposition of various shaped pores.

However, the isothermal nitrogen adsorption and desorption curve of the semi-coke at a final temperature of 900℃ during slow pyrolysis showed a different shape from the other six semi-cokes. After comparison, it is found that the nitrogen adsorption curve of the semi-coke isotherm at 900℃ is type II isotherm, which reflects that the semi-coke has a more continuous complex pore system, and the distribution of micropores, mesopores and macropores is more continuous and complete. The initial part of the adsorption isotherm rises slowly and appears as an upward convex shape. At this time, the semi-coke adsorption gas mainly occurs on the wall of the micropores; afterwards, it rapidly rises when the P/P0 approaches 1, which also indicates the existence of mesopores and macropores. The hysteresis loop of the desorption curve indicates that the shape of the hole is a superposition of a slit hole and a wedge-shaped hole. The different shapes of the semi-coke isothermal nitrogen adsorption and desorption curves also indicate that the pore size distribution is also different, as shown in Figure 2.
3.3. Surface topography analysis

Figure 3 shows the results of SEM analysis of rubber wood char pyrolyzed at 300°C to 500°C. As the temperature increases, the number of large particles on the surface of the char is significantly reduced, which indicates that these substances are gradually melting at high temperatures, volatile substances are gradually released, and the particle size of the char has changed significantly. The results of 1K times SEM analysis at 300°C is shown in Figure 4. After pyrolysis at a lower temperature, the surface structure of rubber wood char still remains the original natural structure and the surface is smooth and non-porous, with only a few particles on the surface. Wang[13] also found that at lower temperatures, the fiber bundle structure in biomass pyrolysis char can be clearly seen; and the surface is relatively smooth, slightly cracked, and no obvious microporous structure.
Figure 3. SEM of char at 300°C to 500°C with 200 times.

Figure 4. SEM of char at 300°C with 1000 times.

Figure 5 shows the surface morphology of char at temperature from 600°C to 900°C. It can be seen that as the temperature to 600°C, the surface of the char begins to appear grooved, with a rough appearance, and some obvious cracks and fractures appear on the surface. It is the result of the violent release of volatiles due to the increase in temperature. These cracks cause the char to split into particles of different sizes, and a small part of the pore structure form. When the temperature reaches 700°C, the number of pores becomes more abundant, the distribution is more ordered, the carbon skeleton structure becomes gradually clear, and the ordered structure of char becomes more obvious. When the temperature rises to 800°C, the thin wall of the small pores collapses, resulting in a larger pore size, and evenly distributed on the surface of the char. As the pyrolysis temperature continues to rise to 900°C, the carbon skeleton undergoes melting and ablation, and biomass char shows some disorder, which may be caused by surface etching [14].
3.4. Surface functional group analysis

The Fourier infrared spectrograms of rubber wood pyrolysis semi-coke prepared at different pyrolysis temperatures are shown in Figure 6. There are abundant functional group structures in rubber wood, such as alkyl groups, ether bonds, aromatic compounds and alcohols. While, the main organic compounds of the semi-coke of rubber wood are classified into three categories: aromatic compounds, aliphatic compounds and oxygen-containing functional groups. In all FT-IR spectra, it can be observed that there is a broad absorption peak between 3800-3200 cm\(^{-1}\). The vibration peaks in rubber wood and its semi-coke are composed of organic compounds with oxygen functional groups (such as phenol, Alcohols and carboxylic acids) caused by the vibration of the \(-\text{OH}\) group. Compared with the original, the \(-\text{OH}\) group in the char decreases significantly, indicating that the pyrolysis of hemicellulose in rubber wood has the lowest thermal stability. Because the tensile vibrations of aliphatic \(-\text{CH}, \text{-CH}_2\) and \(-\text{CH}_3\) are mainly manifested in the presence of bands around 2924 cm\(^{-1}\) and 2853 cm\(^{-1}\). With the increase of the pyrolysis temperature, the tensile vibration of such functional groups in the rubber wood semi-coke are gradually weakened, indicating that the high pyrolysis temperature caused the alkane side chain in the rubber wood to break. The \(-\text{CH}, \text{-CH}_2\) and \(-\text{CH}_3\) groups of the aromatic compounds in the semi-coke are significantly reduced, and the aromaticity of the char increases accordingly. C-O and C=O tensile vibrations will mainly appear at bands around 1728 cm\(^{-1}\) and 1035 cm\(^{-1}\). With the increase of the pyrolysis temperature, the tensile vibration of C-O and C=O in the rubber wood semi-coke basically
disappeared, indicating that the alcohols, ethers and esters, mainly composed of carbonyl groups, have been completely decomposed during the pyrolysis process. The FT-IR spectra of the rubber wood semi-coke prepared at 800 °C basically tends to be flat, indicating that the high temperature promotes the cracking and polycondensation reactions in the rubber wood pyrolysis process; the graphitization and aromatization of the char deepens, the macromolecules aromatic ring structure increases, and a large number of oxygen-containing functional groups and aliphatic structures are broken and precipitated in the form of gas.

The rubber wood was quickly coked at 800°C, and the Fourier infrared spectra of the semi-coke of rubber wood pyrolyzed at different residence times are shown in Figure 7. Comparing the evolution of functional groups in rubber wood under different residence time, there is a significant evolution process of functional groups in rubber wood at high temperature; especially in the wave number stage of 1700-1000 cm⁻¹, tensile vibration of C-O and C=O decreased significantly. Due to the obvious cracking and polycondensation reaction of rubber wood at 800°C, in the initial stage of pyrolysis (30s), rubber wood is not completely pyrolyzed during char forming, and functional groups such as CO and C=O have not enough pyrolysis time and aromatization of char is insufficient. With the increase of pyrolysis residence time, the pyrolysis reaction of volatile substances and the polycondensation reaction of char molecules in rubber wood have been strengthened, resulting in the content of macromolecular aromatic structure increased, the degree of graphitization and aromatization of char deepened, and the char structure stable.
3.5. Surface functional group analysis

In this study, Raman spectroscopy was performed on the rubber wood char produced by pyrolysis, and the first-order Raman spectroscopy was analyzed by the ten-peak method to explore the influence of different heating methods and pyrolysis temperature on the chemical structure of biomass char[15, 16]. In order to facilitate the analysis of the Raman spectrum, after fitting the peaks of the Raman spectrum of the sample, the total peak area $S1$ of the 10 peaks is calculated. Meanwhile the area of the corresponding peaks and the area ratio of the corresponding peaks are also calculated and the characteristic parameters of the Raman spectrum of each sample are obtained, which reflect the biomass char structure.

Figure 8 describes change characteristics of the Raman spectral characteristic parameters $A_{(GR+VL+VR)/AD}$, $A_D/S_1$ and $A_{(GR+VL+VR)/S_1}$ of char, which are produced by fast pyrolysis from rubber wood at temperature of 400°C, 600°C and 800°C. It can be seen from Figure 8(a) that the parameter $A_{(GR+VL+VR)/AD}$ increases first and then decreases. $A_{(GR+VL+VR)/AD}$ represents the relative content of the small and large aromatic rings in biomass char. This trend shows that the increase of the relative content of the small aromatic ring structure is faster than that of the large aromatic ring structure at the lower temperature in the initial stage of pyrolysis. When it is beyond 600°C, the increase of relative content of large aromatic ring is more severe than that of the small aromatic ring. At this stage, the small aromatic ring structure in the char is released under the action of heat, which increases the relative content of the large aromatic ring. From Figure 8(b), it can be found that $A_{(GR+VL+VR)/S_1}$ also decreases after 600°C, indicating that in addition to the release of small aromatic ring structures at this stage, side chains and C-O bridge bond in biomass char break to form a large number of active sites. And these active sites will aggravate the polycondensation of the aromatic ring under the action of heat; so that a large number of small aromatic rings are polycondensed to large aromatic rings. Therefore $A_{(GR+VL+VR)/S_1}$ will decrease, and the aromatization of biomass char will increase. At the same time, $A_D/S_1$ starts to increase significantly after it is beyond 600°C, which also shows that the increase of the relative content of the large aromatic ring structure increases more intense, and the aromatization of biomass char increases.
Figure 8. Raman Characteristic parameters at different rapid pyrolysis temperature (a) $A_{G(R+VL+VR)}/A_D$; (b) $A_D/S_1$and $A_{G(R+VL+VR)}/S_1$.

Figure 9 shows the variation of the Raman characteristic parameter $A_S/S_1$ at three different temperatures for the rapid pyrolysis of rubber wood. From the Figure 9, $A_S/S_1$ shows a downward trend when the pyrolysis temperature increases to 600°C, and then starts to rise with the increased temperature. This indicates that in the initial stage of pyrolysis, the alkane substitution, aliphatic hydrocarbons and cross-linked structure in char decrease with the increased temperature, indicating that the release of alkane substitution and the rupture of cross-linked structures, such as aliphatic hydrocarbons, dominate at this stage. When the temperature is further increased, along with a large number of polycondensation of aromatic rings, the active sites formed by the cleavage of side chains will further form a more stable cross-linked structure such as C-C.

Figure 9. The index of $A_S/S_1$ at different pyrolysis temperature.

Figure 10 shows the variation characteristics of pyrolysis char $A_{GL}/S_1$ with different pyrolysis temperature. It can be seen from the figure that with the increase of pyrolysis temperature, $A_{GL}/S_1$ shows a significant downward trend, indicating that C=O in biomass char structure increases with the temperature in the pyrolysis, which can explain the heat well.
Figure 10. The variation characteristics of AGL/S1 with different pyrolysis temperature.

Figure 11 shows the change characteristics of A(GR+VL+VR)/AD, AD/S1 and A(GR+VL+VR)/S1 of rubber wood which is slowly pyrolyzed at 300°C to 900°C. As shown in Figure 11(a), A(GR+VL+VR)/AD falls continuously in slow pyrolysis, compared with it first rises and then falls in rapid pyrolysis. When it belows 500°C in slow pyrolysis, A(GR+VL+VR)/AD decreases fiercely; and this decrease slows down when it reaches 500°C to 700°C; and when it is beyond 700°C, it slightly increases and then tends to be gentle. At low temperature, A(GR+VL+VR)/AD significantly decreases, indicating that in addition to the release of water in biomass at this stage, the organic structure in char begins to pyrolyze, and the chemical structure begins to change. It can be seen from Figure 11(b) that when the temperature belows 500°C, A(GR+VL+VR)/S1 obviously decreases, and AD/S1 increases obviously, which indicates that the relative content of large aromatic rings increases and the relative content of small aromatic rings decreases. These further shows that the small aromatic ring begins to release under the action of heat. At stage of 500°C to 700°C, A(GR+VL+VR)/AD and A(GR+VL+VR)/S1 continue to decrease, and AD/S1 further increases. At this stage, the cleavage of the bio- char bridge bond produces a large number of active sites. As a result, the small aromatic ring structure begins to polycondensate into a large aromatic ring structure, which further increases the relative content of the large aromatic ring. At stage of 700°C to 900°C, as the polycondensation has reached a high level, if continue to increase the temperature, the degree of polycondensation of small rings into macrocycles will be limited; and there will be a small amount of large aromatic ring structures to pyrolysis into small aromatics ring due to high temperature, resulting in a decrease in AD/S1 and a increase in A(GR+VL+VR)/S1 slightly.

Figure 11. Raman Characteristic parameters at different slow pyrolysis temperature (a) A(GR+VL+VR)/AD; (b) AD/S1and A(GR+VL+VR)/S1.
Comparing Figure 8 with Figure 11, it can be found that the two heating methods of fast pyrolysis and slow pyrolysis have obvious different influence on the chemical structure of biomass char, which reflects the effect of different heating rates on the chemical structure of biomass char. Fast pyrolysis is a violent reaction process, while slow pyrolysis is a relatively slow process. In the case of fast pyrolysis at a lower temperature, due to the violent reaction, rapid pyrolysis generates a large number of small aromatic ring structures. The side chains and bridge bonds of the pyrolysis char are too late to break to form active sites, that is, the small aromatic ring generated is too late to polycondensate to a large aromatic ring structure. The slow reaction is totally contrary. The slowly rising temperature makes the polycondensation of the small aromatic ring greater than the thermal release of the small aromatic ring; so the relative content of the large aromatic ring structure increases more violently than the small aromatic ring. When the temperature is further increased during the rapid pyrolysis process, due to the higher temperature, along with side chains and bridge bonds are broken, a large number of active sites are generated. At the same time, a large number of uncondensed small aromatics are generated at a lower temperature, which promotes the condensation of small aromatic rings into large aromatic rings.

4. Conclusion

The rubber wood under different pyrolysis conditions is prepared for biomass char. Using the methods of BET, SEM, FT-IR and Raman spectroscopy characterization, the structural characteristics of rubber wood char under different conditions of pyrolysis final temperatures, residence times and heating methods are studied and analyzed, and the following conclusions are drawn:

(1) For different final pyrolysis temperatures, at 300°C -800°C during slow pyrolysis, the nitrogen isothermal absorption/desorption curves are different, but basically overlap. While the curves at 900°C have obvious differences. Rubber wood char have a certain number of small pores and micropores. The fast pyrolysis biomass char still retains the long fibrous structure of the original biomass at the beginning. As the pyrolysis temperature increases, small particles, cracks and gullies begin to appear on the surface. When temperature increases further, a more obvious carbon skeleton is generated. The increase in the final temperature of the rapid pyrolysis causes the cleavage of alkane side chain functional groups and the deep aromatization of char. Through Raman spectroscopy, it is known that the increase in temperature can promote the condensation of small aromatic rings into large aromatic rings, which promotes the aromatization of biomass char.

(2) For different residence time, according to FT-IR, different residence time has obvious evolution to rubber wood char functional group. In the initial stage of pyrolysis (30s), rubber wood is not completely pyrolyzed during char molding. Functional groups, such as C-O and C=O, do not experience enough pyrolysis time, and the aromatization of char was insufficient. With the increase of pyrolysis residence time, the pyrolysis reaction of volatile substances in rubber wood and the polycondensation reaction of char molecules have been strengthened, resulting in an increase in the content of macromolecular aromatic structure, and the degree of graphitization and aromatization of char deepened. And the char structure tends to be stable.

(3) Comparing the fast pyrolysis and slow pyrolysis methods, the fast heating method of fast pyrolysis results in that the relative content of small aromatic structures at lower temperatures is greater than large aromatic rings. Contrarily, during slow pyrolysis, the increase of the relative content of large aromatic ring structures is greater than that of the small aromatic ring structure. At higher temperatures, both show the same characteristics, that is, the relative content of the large aromatic ring structure is greater than that of the small aromatic ring structure.

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