

Article

Modified MgH₂ Hydrogen Storage Properties Based on Grapefruit Peel-Derived Biochar

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Abstract: Carbon materials play an important role in the development of solid hydrogen storage materials. The main purpose of this work is to study the low-cost synthesis of biomass carbon (BC) and its positive effect on the hydrogen storage behavior of magnesium hydride (MgH₂). Herein, it is proven that when biomass carbon (BC) is used together with magnesium hydride (MgH₂), biomass carbon can be used as an adsorption and desorption channel for hydrogen. The initial dehydrogenation temperature of MgH₂ + 10 wt% BC composite is 250 °C, which is 110 °C lower than that of pure MgH₂. In addition, the MgH₂ + 10 wt% BC composite system can complete all dehydrogenation processes within 10 min at 350 °C. Meanwhile, 5.1 wt% H₂ can also be dehydrogenated within 1 h at 300 °C. Under the same conditions, MgH₂ hardly starts to release hydrogen. After complete dehydrogenation, the composite can start to absorb hydrogen at 110 °C. Under the conditions of 225 °C and 3 MPa, 6.13 wt% H₂ can be absorbed within 1 h, basically reaching the theoretical dehydrogenation limit. Cycling experiments show that the MgH₂ + 10 wt% BC composite has a good stability. After 10 cycles, the hydrogen storage capacity shows almost no obvious decline. It is believed that this study can help in the research and development of efficient carbon-based multifunctional catalysts.

Keywords: MgH₂; biomass carbon; hydrogen storage performance; recyclability; catalyst



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1. Introduction

At present, the pollution caused by traditional fossil energy to the environment is becoming more and more serious. In response to global climate change, the development of green and pollution-free new energy devices has become a general trend [1,2]. Hydrogen energy is currently known as the ideal ultimate energy source. As a secondary clean energy, hydrogen energy has the great advantages of causing no pollution and providing a high level of energy. Therefore, the application of hydrogen energy in mechanical power devices, such as vehicles and ships, has been widely studied [2]. Unfortunately, in many applications, hydrogen storage technology still restricts the further development of hydrogen energy [3]. In order to provide efficient, safe, and economical hydrogen storage technology, researchers have turned their attention to solid-state hydrogen storage materials [4–6]. Hydrogen metal hydrogen storage materials using metal Mg as the medium have been the focus of global research for many years due to their great advantages of a high hydrogen storage density (7.6 wt%), low price, and abundant available resources. However, the high dehydrogenation temperature of magnesium hydride (MgH₂) is the main bottleneck restricting its practical application. These problems are attributed to the stable thermodynamic properties (75 kJ mol^{−1}) and slow kinetic properties of MgH₂ [7,8].

With the rapid development of advanced carbon materials in recent years, many researchers have found that doping carbon materials in MgH₂ as a catalyst can significantly improve the hydrogen storage performance of MgH₂ [9,10]. Conventional transition metal catalysts usually agglomerate and grow at high temperatures, which greatly compromises

their catalytic performance. In contrast, graphene and its derivatives are considered ideal host materials for supporting and dispersing metal catalysts and MgH_2 due to their large surface area and good electrical and thermal conductivity [11–13]. Several current mainstream carbon materials include reduced graphene oxide (rGO), carbon nanotubes (CNTs) and charcoal (C). Almost all carbon-supported metal catalysts showed a good stability in the cycle test. Porous Ni@rGO nanocomposites were prepared by Liu et al. [14]. During the experiment, they found that the presence of several layers of reduced graphene oxide on the surface of the MgH_2 matrix prevented the agglomeration and sintering of nanoparticles during cycling, significantly enhancing the decomposition stability and cycling stability of MgH_2 . Zhu et al. [15] applied reduced graphene oxide to NiCu solid solution. The experiments confirmed that the rGO matrix played an important role in stabilizing and dispersing NiCu, fully maintaining the catalytic activity. The average decay rate of the hydrogen storage capacity of the composite is only about 0.18 wt%. Gao et al. [16] introduced chain-like carbon nanotube (CNT)-supported CoFeB into MgH_2 to enhance its hydrogen storage performance. The cycling kinetics of the composites remained fairly stable. Even after 20 cycles, the retention rate of hydrogen storage capacity can still be stable at 98.5 wt%. In addition, carbon nanotubes can provide a means of hydrogen diffusion and improve the thermal conductivity of the sample, which can promote the hydrogen absorption and dehydrogenation performance and cycle stability of MgH_2 . On the other hand, Lu et al. [17] conducted research specifically on CNTs. Compared with pure MgH_2 , the dehydrogenation temperature of $\text{MgH}_2 + 10 \text{ wt\% CNTs}$ composites dropped to about 260°C . At 350°C , $\text{MgH}_2 + 10 \text{ wt\% CNTs}$ can complete the dehydrogenation within 20 min. Under the same conditions, the complete dehydrogenation of pure MgH_2 needs to be completed after 35 min. In terms of cycling performance, CNTs also play a crucial role. After the cycle of the composite system, the hydrogen storage capacity and kinetic performance did not show any decline, fully confirming the positive role of CNTs in improving the hydrogen storage performance of MgH_2 . Li et al. [18] synthesized carbon (C)-supported Ni@C nanocrystals using a self-template strategy. They came to a conclusion that in situ-synthesized Ni@C nanoparticles can provide more H "diffusion channels" and active "catalytic sites". Moreover, carbon can significantly improve the tight interface between the catalyst and MgH_2 and prevent the sintering and agglomeration of the catalyst.

Although carbon materials have shown a positive effect in improving the hydrogen storage performance of MgH_2 , the expensive price of carbon materials, such as graphene, increases its limitations. In addition, most high-performance carbon materials are extracted from fossil fuels, which is undoubtedly inconsistent with the essence and original intention of green energy. Therefore, it is vital to find a carbon material with low environmental damage and a low price [19–21]. Biochar is regarded as a promising alternative fuel due to its unique advantages of a simple process, environmental protection, and low price. According to relevant studies, the biomass char prepared from straw and bagasse has a high yield, low heat energy input, and extremely low cost. The preparation prices are US \$0.79 and US \$0.93/kg, respectively. Most importantly, biomass carbon can be used as a catalyst carrier and energy storage material, which undoubtedly has great potential in the process of energy development [22–24].

Due to the excellent improvement effect of carbon materials on MgH_2 hydrogen storage performance, it would be very interesting to prepare efficient and environmentally friendly biomass carbon-based composite hydrogen storage materials and explore their mechanism. In previous studies, there were few reports that biomass carbon improved the performance of MgH_2 . Therefore, through the improved method and using grapefruit peel as a precursor, biomass carbon (BC) was successfully prepared by freeze-drying and calcination reduction. At the same time, it was combined with MgH_2 by mechanical ball milling and compared with the catalytic performance of rGO. In addition, the morphology and catalytic performance of the new carbon material were verified by a series of microscopic characterization methods, and its effect on the adsorption and dehydrogenation behavior

of MgH_2 was investigated. Our laboratory has previously conducted many studies on biomass carbon and MgH_2 , which have a good experimental basis [25,26]. It is believed that this discovery can not only enrich the research work on carbon materials but also provide some references for designing efficient carbon-based multifunctional catalysts for hydrogen storage materials.

2. Experiment

The chemicals were purchased from Sinopharm Chemical Reagent Co., Ltd. (Shanghai, China) and used directly without further purification.

2.1. Preparation of BC and rGO

The preparation process of biomass carbon (BC) is shown in Figure 1. First, peel off the yellow outer layer of grapefruit peel and leave the white part. Then, wash with distilled water 5 times, and cut the white part of grapefruit skin into strips of 2×0.5 cm. Subsequently, place it in a vacuum freeze-drying oven for freeze-drying for 48 hours. After freezing and drying, put the grapefruit peel in the blender and stir it into powder. Finally, take 1 g of grapefruit peel powder in a quartz tube, raise to 460°C at a heating rate of $2^\circ\text{C}/\text{min}$ and hold for 3 h. It should be noted that the nitrogen atmosphere needs to be maintained in the quartz tube. After cooling, biomass carbon can be obtained.

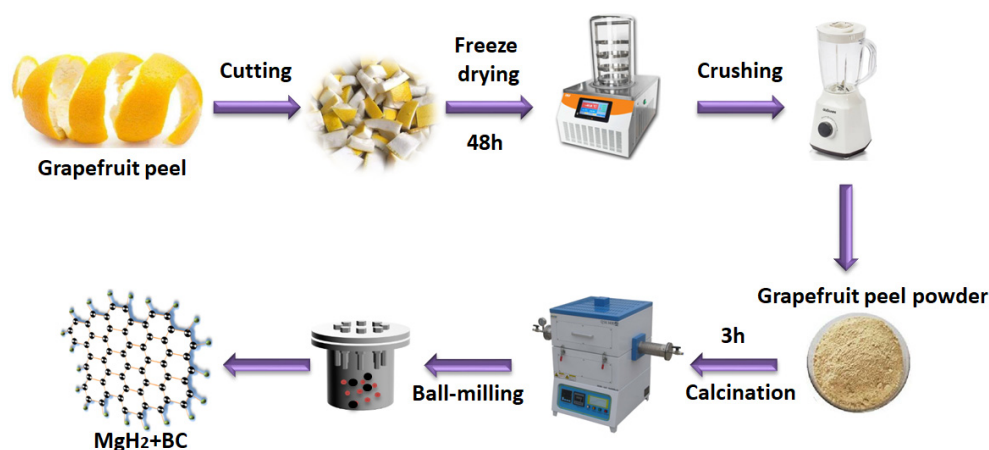


Figure 1. Schematic diagram of synthesis process of $\text{MgH}_2 + \text{BC}$ composite.

Graphene oxide (GO) was prepared by a modified Hummer method [27]. Reduced graphene oxide (rGO) was obtained by pyrolytic reduction. Subsequently, 1 g of GO was put into a tube furnace and heated to 500°C under nitrogen atmosphere and held for 10 min at a heating rate of $2^\circ\text{C}/\text{min}$. After cooling, rGO was obtained.

2.2. Preparation of $\text{MgH}_2 + \text{BC}$ and $\text{MgH}_2 + \text{rGO}$ Composites

First, 6 g of magnesium powder was taken and hydrogenated at 380°C for 1 h with a hydrogen pressure of 7 MPa. Next, the hydrogenated Mg powder was put into a ball-milling tank filled with Ar gas and ball-milled at 450 rpm for 5 h. After ball-milling, the samples were pounded and hydrogenated at 380°C under 7 MPa hydrogen. Repeat this process 5 times to successfully prepared MgH_2 powder. It should be noted that pulverization must be carried out every hour to ensure that the Mg powder can be completely hydrogenated. Next, BC and MgH_2 were put into a ball-milling tank in an Ar atmosphere at a mass percentage of 10:90 and milled for 4 h at a speed of 450 rpm to obtain the finished product, which was recorded as $\text{MgH}_2 + 10 \text{ wt}\% \text{ BC}$. MgH_2 and rGO were mixed in the same way and recorded as $\text{MgH}_2 + 10 \text{ wt}\% \text{ rGO}$. All samples were kept in glove boxes for further analysis.

2.3. Characterization

The samples were characterized by X-ray diffraction (XRD), a scanning electron microscope (SEM), and a transmission electron microscope (TEM). XRD was performed using a D8 X-ray diffractometer (Bruker) with an analysis angle of 10–80° and a scan rate of 5°/min. Cu K α radiation ($\lambda = 1.5406 \text{ \AA}$) was used for the test, the tube voltage was 35 kV, and the tube current was 35 mA. SEM test equipment model was FEG 250 with a working voltage of 20 kV. TEM was characterized using the FEI TALOS 200X equipment to study the microstructure of the samples. The absorption and dehydrogenation experiments of the composites were carried out on self-made Sievert-type equipment, and the test amount of each sample was about 120 mg. The error of high-pressure sensors in Sievert-type equipment was 0.02%, and the error of low-pressure sensors was 0.01%. The isothermal dehydrogenation and hydrogen absorption experiments of the samples were tested after the temperature remained stable. The temperature rise dehydrogenation experiment involved making the equipment temperature rise to 450 °C at 2 °C/min under -0.01 MPa . The temperature-increasing hydrogen absorption experiment was carried out by heating the equipment to 400 °C at 1 °C/min under the hydrogen pressure of 3 MPa. The reason for the difference in heating rate was that the hydrogen absorption kinetics of MgH_2 was better than the dehydrogenation kinetics. The heating rate was too fast and not conducive to data recording and analysis. Cyclic kinetic tests were performed at a constant temperature of 350 °C, and the hydrogen pressure was 3 MPa.

3. Result and Discussion

3.1. Characterization of the BC and rGO

In Figure 2a, the XRD patterns of BC and rGO can be clearly seen. The typical characteristic peaks of 2θ at 24.8° and 43.1° are graphitic structures (002) and (100) planes. Two broad and large diffraction peaks indicate the formation of a highly graphitized carbon skeleton. The broad and gentle bulge with 2θ between 20 and 25° is a sign of amorphous carbon and is a typical amorphous XRD line shape. This is mainly due to the low degree of graphitization and crystallization of amorphous carbon, which is generally an amorphous state. In order to further study their microscopic morphology, we carried out SEM characterizations for both. Figure 2b is the SEM image of BC. It can be found that the layered structure formed by BC in the plane is disordered and irregular. Most of the fragments are stacked roughly parallel to each other and in a disorderly manner, which is the main symbol of the disordered layer structure. The reason for this unique phenomenon is that the formation of surface crystals may be defective. On the other hand, the SEM characterization of rGO was also performed. From Figure 2c, it can be seen that rGO has a transparent layered structure with obvious wrinkles, showing a silk-like appearance. This is mainly due to the reduction of the oxygen-containing functional groups of rGO during the thermal reduction process and the extrusion and agglomeration of rGO occur under the action of van der Waals forces.

In addition, the prepared BC was characterized by TEM in order to observe its microstructure in more detail. Figure 2d shows the high-power TEM photos of BC. It can be seen that the small grains of BC are distributed in a disorderly manner, while the edge structure has no obvious regular shape and contains a small number of impurities, which are mainly incomplete carbonized carbon fibers. This is consistent with the conclusion of low crystallinity in XRD. All the above results mean that the preparation of BC and rGO is successful.

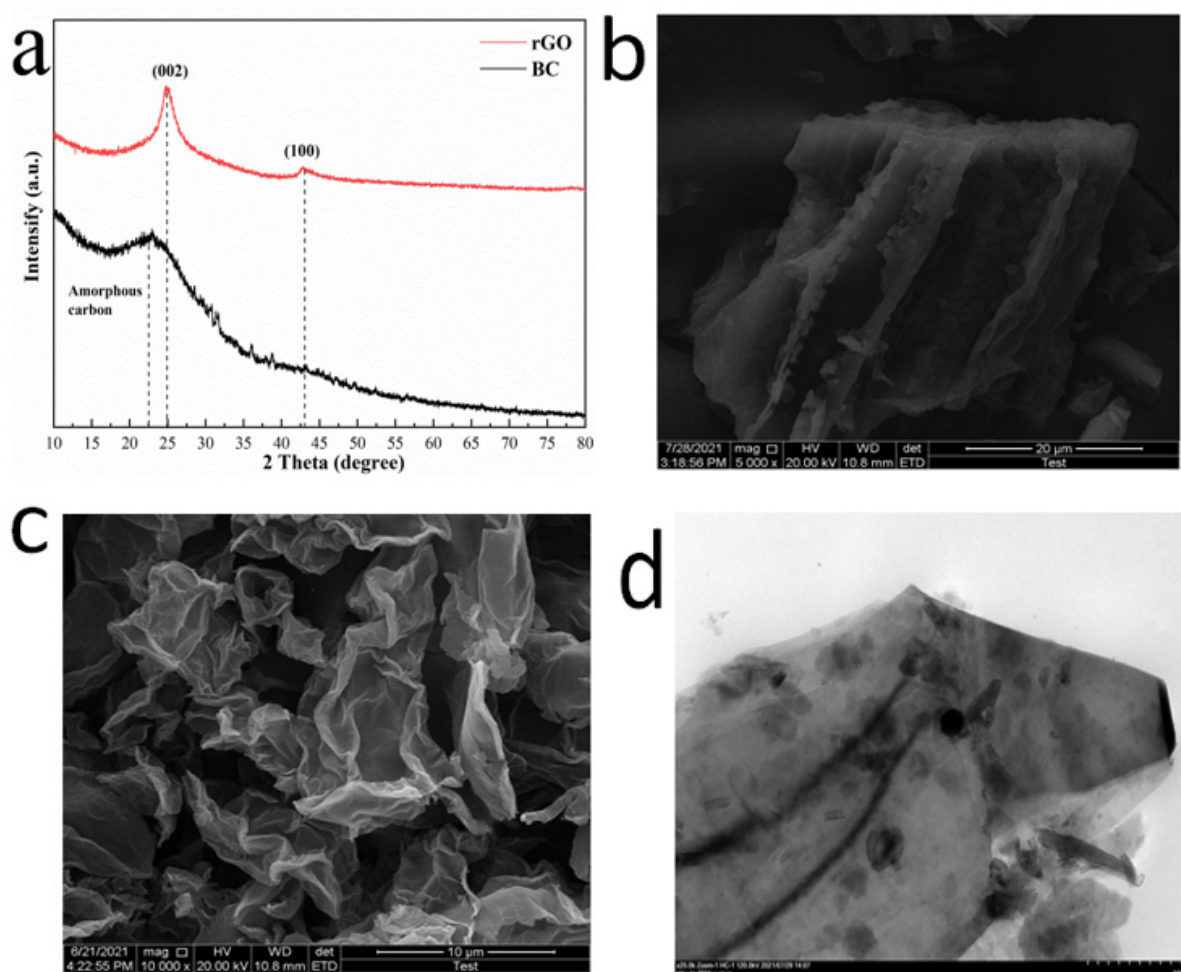


Figure 2. XRD (a) of BC and rGO, SEM of BC (b) and rGO (c), TEM of BC (d).

3.2. Hydrogen Desorption Performances of $\text{MgH}_2 + \text{BC}$ and $\text{MgH}_2 + \text{rGO}$ Composites

In order to verify the improvement effect of BC as an active catalytic material on the hydrogen storage performance of MgH_2 , isothermal and non-isothermal methods were used to study the dehydrogenation performance curves of $\text{MgH}_2 + 10 \text{ wt}\% \text{ BC}$ and pure MgH_2 . For comparison, the same test was also performed on the $\text{MgH}_2 + 10 \text{ wt}\% \text{ rGO}$ composite. It should be noted that the desorption and absorption capacity of hydrogen is based on MgH_2 . It can be seen from Figure 3a that different carbon materials have different effects on reducing the initial temperature of dehydrogenation of MgH_2 . It is worth noting that the onset dehydrogenation temperature of $\text{MgH}_2 + 10 \text{ wt}\% \text{ BC}$ is the lowest. Dehydrogenation begins at around 250°C , which is about 110°C lower than that of pure MgH_2 . Moreover, the dehydrogenation temperature of the composite is also about 20°C lower than that of $\text{MgH}_2 + 10 \text{ wt}\% \text{ rGO}$. Figure 3b–d are isothermal hydrogen absorption experiments. It can be seen from Figure 3b,c that the $\text{MgH}_2 + 10 \text{ wt}\% \text{ BC}$ composite can complete all dehydrogenation processes within 10 min at 350°C . Under the same conditions, $\text{MgH}_2 + 10 \text{ wt}\% \text{ rGO}$ composite takes a longer time to complete dehydrogenation. When the temperature is kept at 325°C , the $\text{MgH}_2 + 10 \text{ wt}\% \text{ BC}$ composite system can be completely dehydrogenated within 30 min, while the $\text{MgH}_2 + 10 \text{ wt}\% \text{ rGO}$ composite needs about 35 min. Even at 300°C (Figure 3d), $\text{MgH}_2 + 10 \text{ wt}\% \text{ BC}$ exhibited the fastest dehydrogenation kinetics. Within 30 min, $\text{MgH}_2 + 10 \text{ wt}\% \text{ BC}$ and $\text{MgH}_2 + 10 \text{ wt}\% \text{ rGO}$ composites can release $3.37 \text{ wt}\%$ and $2.16 \text{ wt}\%$ H_2 , respectively. On the contrary, MgH_2 has almost no hydrogen evolution within 30 min. Even within 1 h,

MgH₂ evolved only 0.9 wt% H₂, which was similar to the isothermal dehydrogenation results of MgH₂ + 10 wt% BC composite at 275 °C.

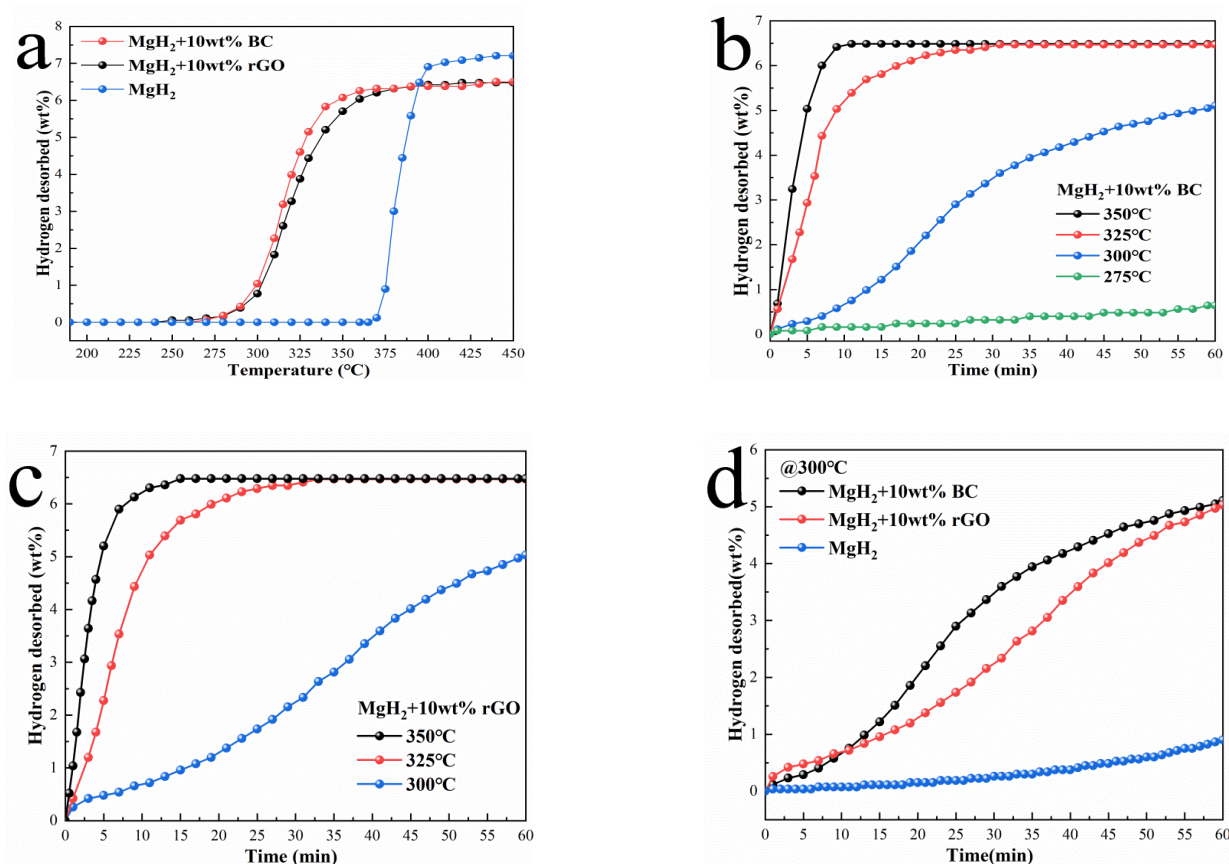


Figure 3. The rising temperature dehydrogenation curve of (a) MgH₂ + 10 wt% BC, MgH₂ + 10 wt% rGO and MgH₂. Isothermal dehydrogenation curves of (b) MgH₂ + 10 wt% BC and (c) MgH₂ + 10 wt% rGO. Isothermal dehydrogenation curve prepared at 300 °C for (d) MgH₂, MgH₂ + 10 wt% BC, MgH₂ + 10 wt% rGO.

3.3. Hydrogen Absorption Performances of MgH₂ + BC Composites

In view of the positive improvement effect of biomass carbon on MgH₂ hydrogen storage performance in the dehydrogenation test, the effect of biomass carbon on MgH₂ hydrogen absorption kinetics was studied. The heating and constant temperature hydrogen absorption properties of MgH₂ + 10 wt% BC and MgH₂ were tested, respectively, as shown in Figure 4a. The initial hydrogen absorption temperature of MgH₂ + 10 wt% BC under the hydrogen pressure of 3MPa is about 110 °C. When the temperature reaches 290 °C, the theoretical hydrogen absorption has been reached. Under the same conditions, pure MgH₂ needs to start to absorb hydrogen slowly at about 150 °C. Hydrogen absorption is not substantially complete until at 340 °C. Figure 4b,c shows the gap between the two in more detail. It can be found that MgH₂ + 10 wt% BC can absorb about 6.13 wt% H₂ at 225 °C. However, pure MgH₂ only absorbed 5.78 wt% H₂ at 230 °C. The hydrogen uptake of MgH₂ + 10 wt% BC composites at 200 °C is almost similar to that of pure MgH₂ at 210 °C. This consequence shows that biomass carbon has indeed shown a positive effect on the improvement of the hydrogen absorption performance of MgH₂, which can effectively improve the hydrogen absorption kinetic performance of MgH₂.

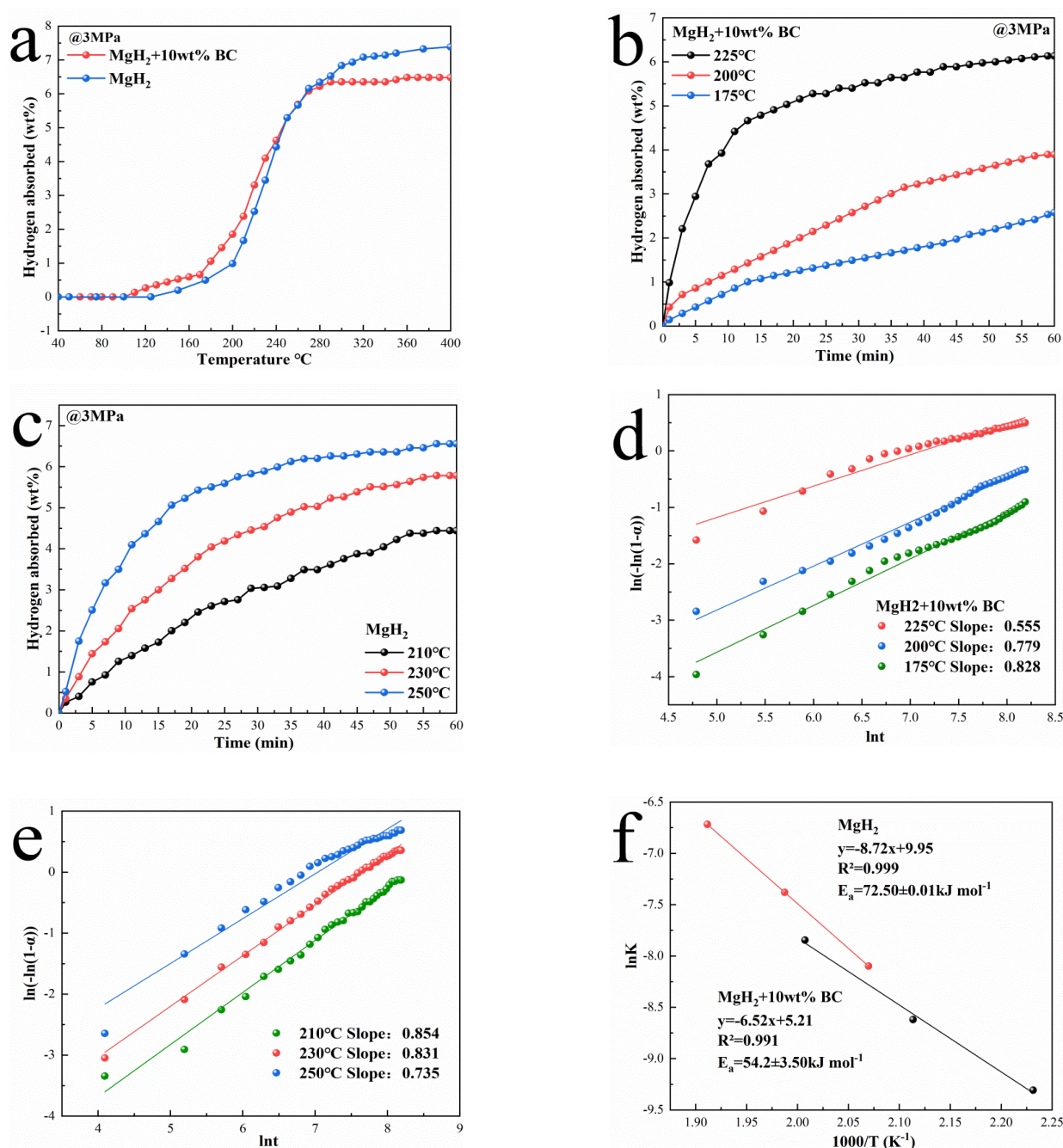


Figure 4. Non-isothermal hydrogenation curves of (a) $\text{MgH}_2 + 10 \text{ wt}\% \text{ BC}$. Isothermal hydrogen absorption curves at different temperatures of (b) $\text{MgH}_2 + 10 \text{ wt}\% \text{ BC}$ and (c) pure MgH_2 . JMAK plots for (d) $\text{MgH}_2 + 10 \text{ wt}\% \text{ BC}$ and (e) MgH_2 . Arrhenius plots for (f) MgH_2 and $\text{MgH}_2 + 10 \text{ wt}\% \text{ BC}$.

In order to more intuitively see the difference between the two hydrogen absorption effects, this paper uses the hydrogen absorption activation energy to calculate the energy required for the material to change from the normal state to the active state. The Johnson–Mehl–Avrami–Kolmogorov (JMAK) equation can simulate and calculate the apparent activation energy E_a of the hydrogen absorption reaction between MgH_2 and the composite system after complete hydrogen evolution. The JMAK Equation (1) is as follows [28]:

$$\ln(-\ln(1-\alpha)) = n(\ln k + \ln t) \quad (1)$$

where α represents the mass fraction of Mg converted to MgH_2 in time t , k represents the effective kinetic parameter, and n represents the Arrhenius Avrami index.

Figure 4d,e show the JMAK curves of $\text{MgH}_2 + 10 \text{ wt\% BC}$ and pure MgH_2 . According to the experimental data of isothermal hydrogen absorption, the functional relationship diagram of $\ln(-\ln(1 - \alpha))$ and $\ln t$ is made based on different temperatures. It can be seen that the linear fit of each curve is better at different temperatures. From this calculation, their slopes can be derived. Then, the apparent activation energy of the hydrogen absorption reaction was calculated by the Arrhenius equation. First, a functional relationship diagram between $\ln k$ and $1000/T$ was made and fitted again, where $\ln k$ was the ordinate and $1000/T$ was the abscissa. The apparent activation energy E_a of hydrogen absorption was further calculated from the slope of the fitted straight line. The Arrhenius specific Equation (2) is as follows [29]:

$$k = A \exp\left(-\frac{E_a}{RT}\right) \quad (2)$$

The calculated activation energy diagram is shown in Figure 4f. It can be found that the fitting degree of the curve is perfect, and the value of fitting degree R^2 is above 0.99. It is worth noting that the activation energy of hydrogen absorption of $\text{MgH}_2 + 10 \text{ wt\% BC}$ composite is only 54.2 kJ mol^{-1} , while that of pure MgH_2 is 72.5 kJ mol^{-1} . Compared with pure MgH_2 , the apparent activation energy of hydrogen absorption in the $\text{MgH}_2 + 10 \text{ wt\% BC}$ composite system decreased by more than 25%. It can be seen that the addition of BC significantly reduces the chemical energy barrier of the hydrogen absorption process, which has a positive effect on improving the hydrogen absorption kinetics of MgH_2 .

3.4. Cycling Performance of $\text{MgH}_2 + 10 \text{ wt\% BC}$ Composite System

Cycling stability is one of the most important indicators for evaluating the hydrogen storage performance of materials. Therefore, we performed cyclic kinetics tests for $\text{MgH}_2 + 10 \text{ wt\% BC}$ at a constant temperature of 350°C . As shown in Figure 5a,b, the dehydrogenation time of each cycle is 20 min, and the hydrogen absorption time is 10 min. In the first cycle, the de/rehydrogenation of the composites were both 6.35 wt%. With the increase in the number of cycles, the adsorption and dehydrogenation capacity of the material fluctuated slightly but remained basically stable. When the 10th cycle is reached, the hydrogen storage capacity of the material is 6.24 wt%, which is only about 0.11 wt% attenuated compared with the first cycle. This is enough to demonstrate the excellent cycle reversibility of $\text{MgH}_2 + 10 \text{ wt\% BC}$, and the hydrogen storage capacity of the composite remains above 98%. It is clear that the presence of BC aids in the dissociation and adsorption of hydrogen. According to previous research reports, carbon materials can lead to the weakening of Mg-H bond in MgH_2 . This weakening of bond energy is proved to be due to the charge transfer to the edge of carbon material, which affects the charge supply between Mg and H [30]. On the other hand, to further demonstrate the positive role of BC in the MgH_2 cycling experiments, its microstructure was analyzed by SEM. From Figure 5c,d, it can be found that the particle size of the $\text{MgH}_2 + 10 \text{ wt\% BC}$ composite does not increase significantly after the cycle test and maintains good particle uniformity. Although the crystal size must have agglomerated and grown due to high-temperature sintering, it can be seen from the SEM diagram that there is almost no obvious agglomeration growth. Figure 6 shows the XRD patterns of different composites at different stages. Due to the small amount of doped BC and rGO, the diffraction peak of carbon is not very obvious, and it is only slightly raised between $22\text{--}25^\circ$ [31,32]. In addition, it can be found that no matter what kind of catalyst it is, it has good stability after hydrogen desorption and reabsorption. Except for a small amount of MgO, no other substance is produced. After ten cycles, the diffraction peak of Mg appears. This is due to the agglomeration and sintering of the material; a small amount of Mg cannot be hydrogenated again [33]. Generally speaking, the MgH_2 -10 wt% BC catalyst is very stable.

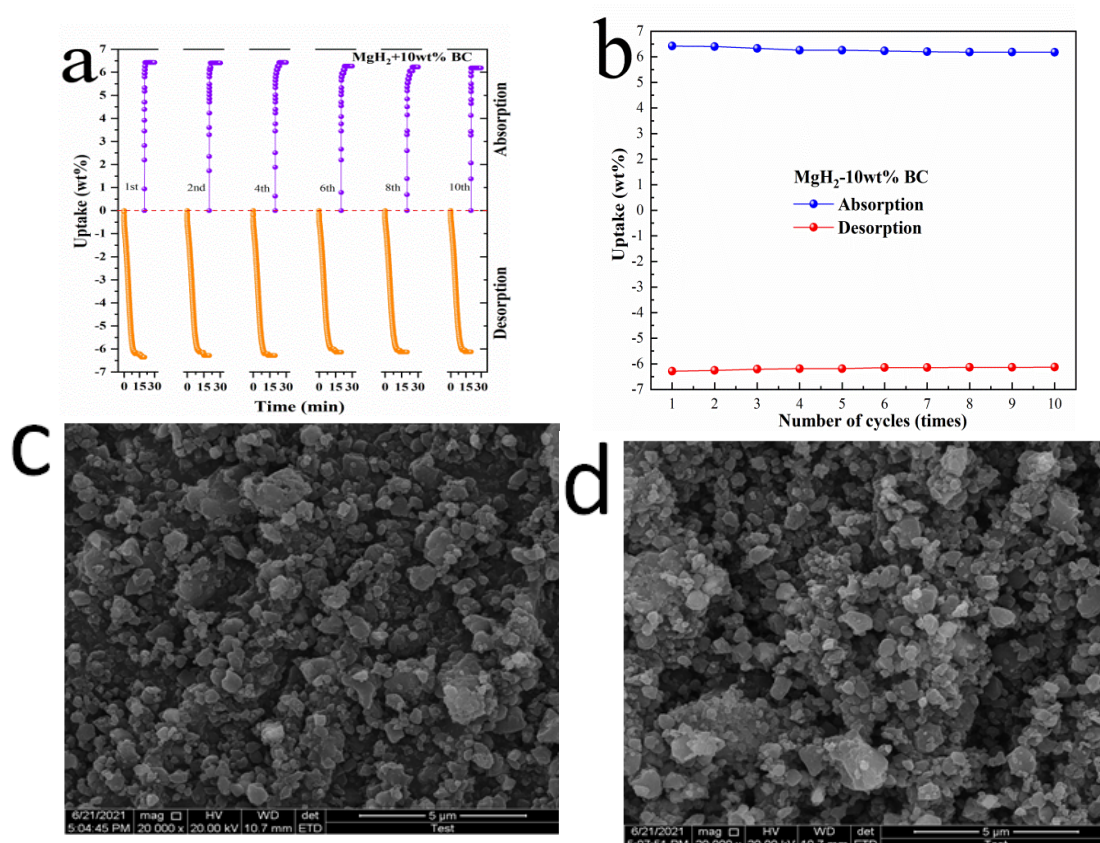


Figure 5. Hydrogen absorption and desorption cycle curves of (a) $\text{MgH}_2 + 10\text{ wt\% BC}$ and at 350°C . Curves showing the (b) hydrogen storage capacity of the system and the discharge over a number of cycles. SEM images of (c) $\text{MgH}_2 + 10\text{ wt\% BC}$ after ball-milling and (d) $\text{MgH}_2 + 10\text{ wt\% BC}$ after the 10th hydrogen absorption.

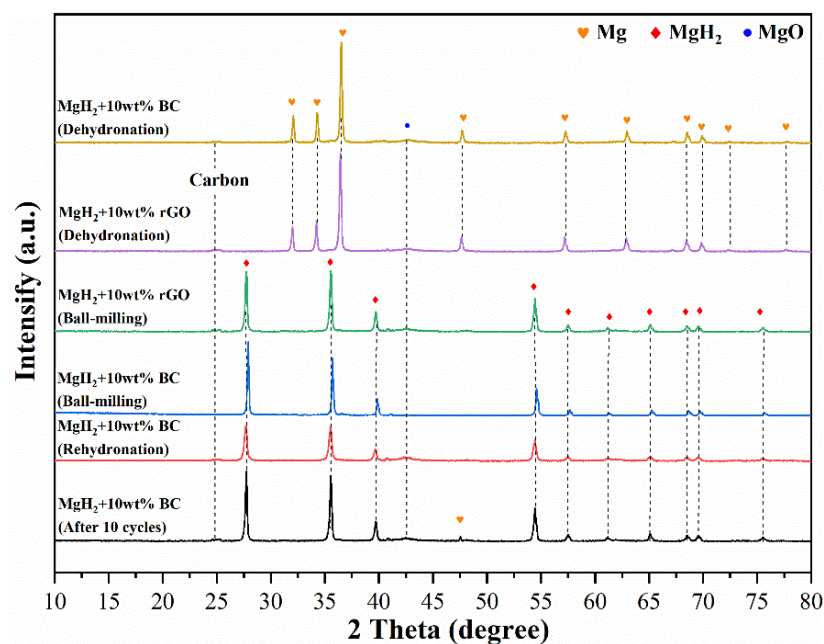


Figure 6. XRD patterns after ball milling and hydrogen dehydrogenation for $\text{MgH}_2 + 10\text{ wt\% BC}$ and $\text{MgH}_2 + 10\text{ wt\% rGO}$. XRD pattern of $\text{MgH}_2 + 10\text{ wt\% BC}$ after rehydrogenation and 10 cycles.

4. Conclusions

Adhering to the idea of green and environmental protection, biomass carbon (BC) was prepared from waste grapefruit peel by a simple freeze-drying and calcination method. At the same time, it was proven that BC plays a positive role in improving the hydrogen storage performance of MgH_2 . Specifically, the initial dehydrogenation temperature of $\text{MgH}_2 + 10 \text{ wt\% BC}$ was 250°C , whereas that of pure MgH_2 was 360°C . In the isothermal dehydrogenation experiment, $\text{MgH}_2 + 10 \text{ wt\% BC}$ could be completely dehydrogenated within 10 min at 350°C , which was better than $\text{MgH}_2 + 10 \text{ wt\% rGO}$ composite and pure MgH_2 . $\text{MgH}_2 + 10 \text{ wt\% BC}$ could still release 5.11 wt% H_2 within 1 h at 300°C . In the same case, the hydrogen evolution of pure MgH_2 was less than 1 wt%. In addition, in the hydrogen absorption kinetics test, $\text{MgH}_2 + 10 \text{ wt\% BC}$ began to absorb hydrogen at 110°C , about 40°C lower than pure MgH_2 . Pure MgH_2 needed a higher temperature to achieve the same hydrogen absorption under the same conditions. Further analysis showed that the doping of biomass carbon significantly reduced the hydrogen absorption apparent activation energy of MgH_2 . The apparent activation energy of hydrogen absorption of $\text{MgH}_2 + 10 \text{ wt\% BC}$ was more than 25% lower than that of pure MgH_2 , which greatly reduced the activation energy barrier of MgH_2 . The cycle dynamics test showed that $\text{MgH}_2 + 10 \text{ wt\% BC}$ ultimately did not show an obvious decline in 10 cycles, and the composite system could still maintain more than 99% of the hydrogen storage capacity after 10 cycles. It was proven that the porous structure of biochar could disperse the MgH_2 matrix well and provide effective hydrogen transfer channels for composites. Moreover, biomass carbon could prevent the sintering and agglomeration of materials at high temperatures so as to improve the cycling performance of materials. In general, the biomass carbon derived from grapefruit peel has the advantages of a lower price, better performance, and green environmental protection compared with traditional carbon materials. It appears very promising to replace traditional carbon-based materials as the carriers of metal catalysts in hydrogen storage and other fields.

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Conflicts of Interest: There are no conflicts to declare.

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