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Effect of Computer Image Process Technology-Based Carbon Fibre Length and Arrangement on Pore Structure

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The effects of length and arrangement of carbon fibers on the pore structure formed by the accumulation of carbon fibers are discussed using two-dimensional network model and computer image processing technology. The results show that with the increase of carbon fiber length, the pore size distribution becomes wider and the average pore size and standard deviation increase. The porosity uniformity first deteriorates and then increases after the fiber length reaches a certain level. With the increase of carbon fiber in the plane X, Y, the difference in orientation arrangement increases. The pore size distribution and the standard deviation of the average pore diameter and the pore diameter are basically the same, but the porosity evenness is deteriorated. Therefore, in order to prepare carbon fiber paper meeting the requirements of mass transfer of proton exchange membrane fuel cells, the fiber length should be as long as possible under other parameters, and the arrangement should be as uniform as possible in all directions in the plane.

1. Introduction

1.1 Carbon Fiber development

As the brace medium of gas diffusion layer in Proton Exchange Membrane Fuel Cell (PEMFC), the pore structure of carbon fibre paper has a great influence of cell system operation (Fei et al., 2014). The pore structure mainly aims to provide the flow channel for electric-chemical reacted H2 and O2 for ensuring the stable current output in cell system, and to discharge the generated liquid water out of system for avoiding flooding. Therefore, it should satisfy the following requirements: the homogeneous porosity to ensure the same quantity of reactant gas in the catalyst layer, the uniform electrochemical reaction rate to avoid the effect of ring current on output, and the certain distribution of inter-fibre pores to form different mass transfer paths and meet the requirement for two phase mass transfer. Fig.1 depicts the scanning electron micrograph (SEM) photograph of the carbon fibre paper by Toray company (Alin et al., 2014). It can be seen in the figure that the carbon fibre paper mainly consists of the carbon fibre-constructed fibre network and binder-based carbon; the pore structure of fibre network is the key path of gas-liquid two-phase mass transfer. In the fibre network, the pore structure must be affected by the fibre length; besides, in the wet papermaking process, the fibre tends to be oriented towards the slurry flow direction, and the fibre of the filtered paper shows different arrangement in X and Y direction, which also influences the pore structure (Bell et al., 2016).
Now few related researches have been made. In this paper, the experiment was conducted to investigate the effect of fibre length and arrangement on the pore structure of fibre network; by applying the 2D model in the paper structure, the computer image processing (CIP) method was then adopted to analyse the pore features and then study its influencing rule, so as to provide a certain theoretical basis for the carbon fibre paper making, with the appropriate pore structure for PEMFC (Li et al., 2011).

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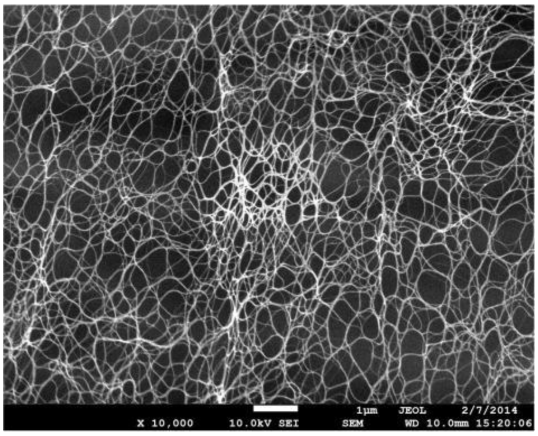

Figure 1: SEM photos of carbon paper

1.2 Computer image processing technology-2D network model

Regarding the fibre network, Cotre et al. proposed one classical 2D network model: on one 2D surface no mutual interference exists between the fibres, the included angle between the fibres can be randomly selected, and the probability for two more fibres on every point is lower than 1% (Heim et al., 2013). It is shown in Fig.2, with larger area in Fig.2(a) and small area in Fig.2(b). In the real paper structure, the probability for each plane point to be covered by fibre is beyond over the coverage rate in 2D network model, but because the paper fibre is basically parallel to the paper plane, and the paper can be regarded as one stacked with multiple 2D network model layers. For the 2D network model, due to lower coverage rate, all fibres are taken on the same plane, and the polygon by fibres is regarded as a pore (generally use the equivalent radius, that of the circle with the same area as the polygon). Based on the research of Abdel-Ghnai et al., the fibre pore- size distribution obtained in the method above was very similar to that of real network in the experiment, it is completely feasible to study the pore structure of real paper by analysing the average equivalent radius and its distribution methods of the formed polygon between fibres in the 2D network model (Hirano et al., 2014).

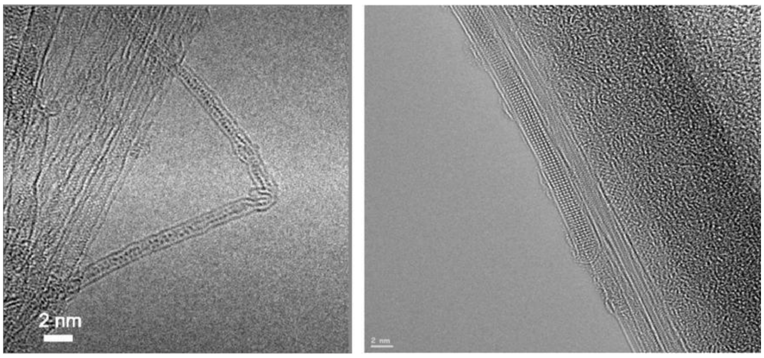

Figure 2: Image of 2D fibre network

2. Computer image processing technology-2D network model detail

2.1 2D network model

In view of the limitation with computer memory and computation speed, the 10mm-long 2D network structure was simulated in the experiment. Based on the definition of 2D network model (Yue et al., 2017), let the probability for each point covered by two more fibres 1%, it can be calculated as:

$$1-\left(P(0)+P(1)+P(2)\right)=0.01 \quad (1)$$

Where P (0), P (1) and P (2) are the probabilities for each point covered by 0, 1 and 2 fibres respectively. Due to no mutual disturbance between the fibres, the coverage probability of the points is given as the results of Rezaei Fsld.

$$P(c)=\frac{\bar{c}e^{-\bar{c}}}{c!},\qquad c=0,1,2,... \tag{2}$$

where, $\hat{C}$ is the average coverage rate of plane points.
So, the average rate is about 0.436, then by Formula (3)[9], based on carbon fibre diameter, linear density, simulated domain area, the carbon fibre mass required by 2D model is calculated as:

$$\bar{c}=\frac{\bar{\beta}\omega}{\delta} \tag{3}$$

Where: $\hat{B}$-paper density, g/m2; ω-fibre diameter, m; δ-fibre linear density, g/m.
The 2D network models in different fibre length and arrangement conditions were constructed by Matlab software. To ensure the model reliability, it was repeated for 10 times when every model in the same condition was constructed, and the average of 10 images was taken for analysis.

2.2 Carbon fibre pore structure analysis

To reflect the pore structure of carbon fibre paper more truly, the generated 2D network model image should be processed with greying and binarization, and then the dilation/erosion treatment should be made for the image to eliminate the isolated pixel points and fibre fines (Wang et al., 2013).
Pore size distribution: treat the void polygon area enclosed by lines as pores, and calculate the spectral distribution of equivalent diameter (Fsld et al., 2009).
Porosity homogeneity: separate the image into the x×x square, and calculate the standard deviation of porosity for all small squares (Cggde et al., 2010).

3. Experiment simulation

3.1 Simulation parameter configuration

Fibre parameters include: T300 carbon fibre of Toray company, 1.76g/cm3 density, and 7μm filament diameter. The fibre length is 3mm, 5mm, 10mm, 15mm and (10+2) mm; the difference of fibre arrangement is 1:1, 2:8, 3:7, and 4:6; (10+2) mm means that the 10mm fibre and 2mm fibre occupies 1/2 of total mass respectively. The difference of fibre arrangement is the probability ratio of X axis and Y-axis on the plane; the 1:1 indicates the same orientation for both axis, and the evenly-distributed arrangement of fibres in each direction.
Fig.3 depicts the generated 2D network image, where Fig.3(a) refers to 3mm fibre length, at the arrangement ratio 1:1; Fig.3(b) is for fibre length 10mm, at the ratio 3:7. The feature of pore structure would be analysed in the following section.

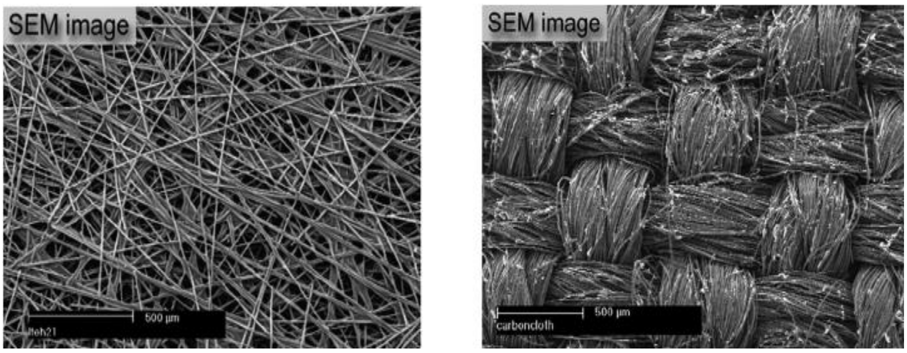

Figure 3: 2D fibre network generated

3.2 Effect of fibre length on pore size distribution

Fig.4 and 5 depicts the effect of fibre length on the pore size distribution and pore size parameters respectively. It can be seen in figures that with the fibre length increasing, the pore size distribution is gradually widened, the number-average pore diameter and weight-average diameter increase, because the increased fibre length can loosen the fibre skeleton and enhance the porosity so as to facility the mass transfer of gas diffusion layer; at the same time, the deviation of pore diameter increases accordingly, indicating the increase of pore diameter variation amplitude and tendency for dispersed distribution. In addition, compared with short fibre network, the long fibre has micropores and macropores. During the operation of fuel cell, the micropore can transfer the liquid water, and macro-pore is for gas transfer to ensure the stable operation state. The pore feature of (10+2) mm fibre network is between 5-10mm, so it is obvious that the mixture of long and short fibre can generate the network with pore feature between these two lengths.

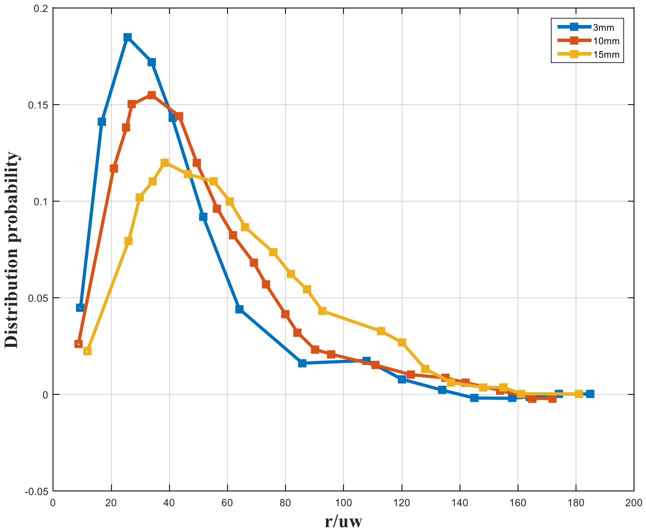

Figure 4: The effect of Fibre length on pore diameter distribution

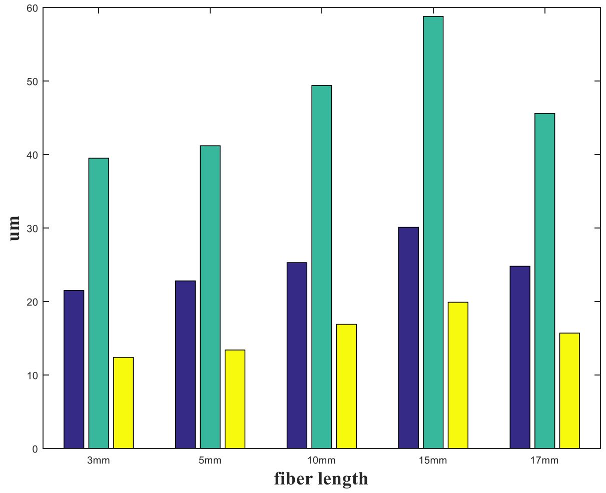

Figure 5: The effect of fibre length on pore diameter parameter

3.3 Effect of fibre length on porosity homogeneity

Fig.6 depicts the effect of fibre length on standard deviation of porosity, where different curves stand for the small squares with selected side length. It can be seen in the figure that with the fibre length increasing, the standard deviation of porosity firstly increases and then decreases continuously, indicating that the porosity homogeneity rise with the fibre length. The simulation results show that the 5mm fibre length can result in the worst homogeneity of porosity, therefore, in the actual carbon fibre paper making process, to ensure the porosity homogeneity, the fibre length should be over 5mm; considering the dispersion in water, it is better to be about 10mm.

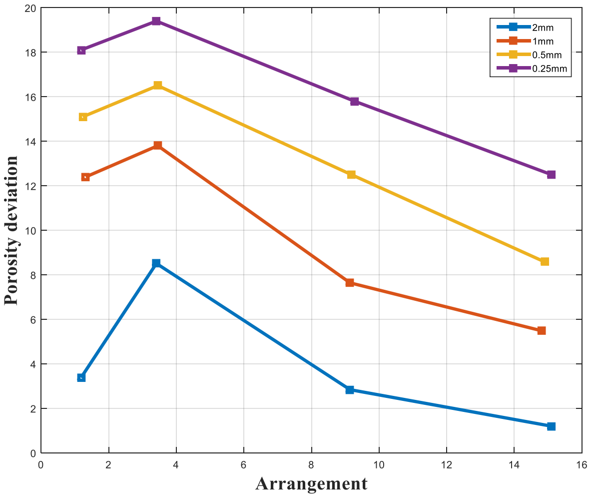

Figure 6: The effect of Fibre length on standard deviation of porosity

3.4 Effect of Fibre arrangement on the porosity homogeneity

Fig.7 depicts the effect of fibre arrangement on standard deviation of porosity. It can be seen in the figure that with the fibre arrangement difference in the X-axis and Y-axis increasing, the standard deviation of porosity rises and the pore uniformity gets worse, but it varies monotonously, without the turning point. Hence, to ensure the porosity homogeneity, the fibre orientation should be minimized to ensure the even arrangement of fibres in the plane.

Above all, for the fibre network, the carbon fibre length should be about 10mm to meet the operation requirements of PEMFC, which also conforms to its related official report; the evenly arrangement should be made in the plane to minimize the fibre orientation caused by slurry flow. Besides, it is certain that the binding materials have certain influence on the paper pore structure, reducing the porosity and centralizing the pore size distribution, therefore, further studies should be made for the adjustment of carbon paper pore structure in future.

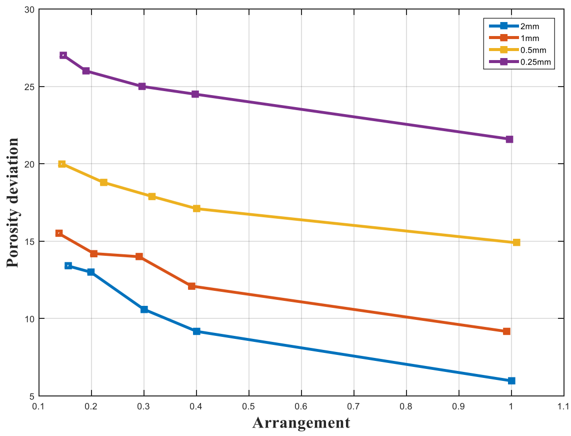

Figure 7: The effect of fibre arrangement on standard deviation of porosity

4. Conclusion

The length and length of the fiber mixture corresponded to the fibers with the length, and the porosity uniformity increases. The fiber arrangement has no effect on the pore size distribution and the pore size parameters; however, the uniformity of the porosity decreases with the difference in the in-plane arrangement of the fibers. In order to prepare a carbon fiber paper meeting the mass transfer requirements of the fuel cell gas diffusion electrode, the length of the carbon fiber should be as long as possible under the condition of satisfying good dispersion. The difference in arrangement in the plane should be as small as possible, preferably uniform. The pore size distribution and the standard deviation of the average pore diameter and the pore diameter are basically the same, but the porosity evenness is deteriorated. Therefore, in order to prepare carbon fiber paper meeting the requirements of mass transfer of proton exchange membrane fuel cells, the fiber length should be as long as possible under other parameters, and the arrangement should be as uniform as possible in all directions in the plane.

Acknowledgments

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