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Damage Mechanism of PVC and Balsa Wood Used in Wind Turbine Blade under Thermal Effect of Lightning Strikes

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Abstract—**At present, PVC and balsa wood are usually adopted in the sandwich structure of the wind turbine blade. However, comparative research on the damage characteristics of the two materials under lightning arc is seldom reported. Large current experiment was conducted on PVC and balsa wood, which indicated that under the surge current, there was a more severe reduction in the residual strength of PVC than balsa wood. By the means of molecular reaction dynamics, the chemical reaction process, gas generation characteristics and water motion of the materials were studied quantitatively. As is shown in the visual results, cellulose (main component of balsa wood) was gradually splitting with the degree of polymerization(DP) reducing as time increasing, while there is no obvious change on the DP in the PVC aspect. The degradation of cellulose generated relatively more kinds of small-molecule gases while PVC mainly produced HCl and small amounts of olefins, but the number of gas products from PVC pyrolysis was far much more than that of cellulose. In addition, with many –OH 、H and O included in cellulose, there are more H_2O molecules absorbed on the cellulose by H bond, which results in a large amount of water content in balsa wood, while, the density of H bond between PVC and water was much lower. Water around the surface of cellulose would turn into vapor that would expand when heated, making it a key factor to the damage of cellulose.**

Keywords-lightning induced arc; wind turbine blade; chemical pyrolysis; molecular reaction dynamics; gas characteristics; water motion

I. Introduction

Wind power generation has got rapid development all over the world these years, but because of its open environment and tall structure, lightning strike failure has become a big question urgent to be solved. Especially, the blade damage is proved to be the most costly.

The blade skin is designed to be sandwich structure, and PVC and balsa wood are usually adopted in the middle layer. When lightning strikes on the blade material, induced arc exists and breakthrough the blade skin. The thermal effect of the induced arc can burn PVC and balsa wood into damage, which produces gas of low molecular to result in lamination phenomenon[1,2]. In another aspect, water moisture in the porous materials expands when temperature increases sharply[3,4], all of the above leads to the mechanical damage of the blade materials. To reveal the damage characteristic of PVC and balsa wood, deep analysis on the chemical reaction process should be conducted.

Plenty of study has been done on the pyrolysis mechanism and also the gas production of PVC and wood, however, traditional experiments hardly provides quantitative results. With the development of computer technology, molecular simulation has gained more and more attention. Especially, Adri C. T. van Duin and Siddharth Dasgupta put forward ReaxFF in 2001 and the new reactive force field can be used to calculate reaction process. Molecular simulation offers a new method to study the degradation mechanism of PVC and balsa wood under lightning induced arc[5].

This paper adopts molecular simulation to study the degradation mechanism of PVC and balsa wood, also the gas production and water steam, which helps to compare the damage characteristics of PVC and balsa wood. Research findings of this paper can instruct selecting the blade materials and designing the material structure.

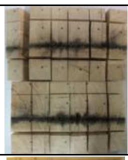
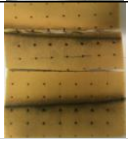
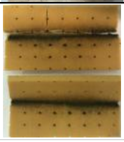
II. LARGE CURRENT EXPERIMENT

A. Sample Preparation and Experimrntal Method

PVC and balsa wood were cut into cuboid with size of 15cm×10cm×2cm, and two piece of the materials were fixed together by insulating tape with nickel chrome wire (diameter of 1m)to ignite the arc, as shown in Fig. 1.

Impulse current with peak values of 1.45kA，6.28kA，12.56k and 21kA were conducted on the nickel chrome wire. After the experiment, scanning electron microscope (SEM) was used to observe the damage morphology, and residual strength was measured to characterize the damage degree.

TABLE I. DAMAGE SAMPLES AFTER THE EXPERIMETS

Materials	Peak value of current（kA）			
	1.45	*6.28*	*12.56*	*21*
balsa wood				
PVC				/

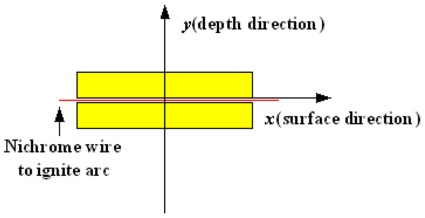


Figure 1. Experimental sample sketch

B. Damage Characteristic of PVC and Balsa Wood

Material damage under different current peak values is shown as TABLE 1. Upper layer of PVC broke off when the peak value increased to 6.28kA, while balsa wood fragmented until the peak value reached 21kA

To comparatively study the damage degree of PVC and balsa wood, the residual strength in the depth direction was measured, as shown in Fig. 2 and Fig. 3. The residual strength decreased obviously as peak value of the current increased, and the decreasing speed of the PVC was larger than the balsa wood.

III. MOLECULAR REACTIVE DYNAMICS SIMULATION ON THE DEGRADATION MECHANISM OF PVC AND BALSA WOOD

Pyrolysis resulted from the thermal effect of the large current can reduce the mechanical strength of PVC and balsa wood, and the expansion stress from generated gas and water steam further aggravates the damage degree of the two materials.

A. Model Construction and Simulation Method

Amorphous cell of two materials with same volume were built using the Builder module of ADF, considering the actual degree of polymerization (DP) and water moisture of PVC and balsa wood(water moisture of PVC and balsa wood after the experiments is shown as Fig. 4), and also to save the calculating time, 1 cellulose molecular with DP of 16 and 12 H_2O, 12 PVC molecular with DP of 3 and 2 H_2O were respectively added in the cells. Target density were set as 1.599g/cm^3 and 1.35 g/cm^3, and the molecular model are shown in Fig. 5 and Fig. 6.

After the molecular models were built, and ReaxFF in ADF was adopted to calculate the chemical reaction under the temperature curve as shown in Figure 7 with peak values 1498K、1698K and 1898K respectively.

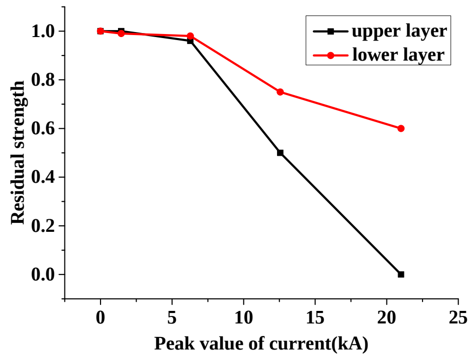


Figure 2. Curve of residual strength *vs* current peak value(balsa wood)\

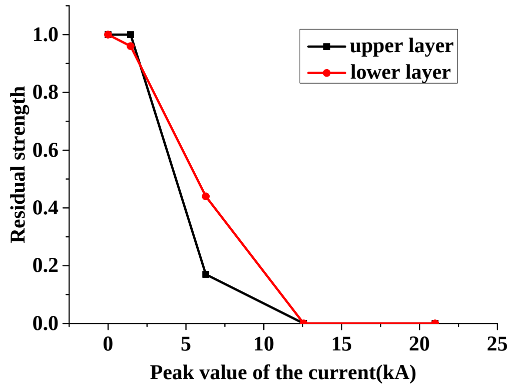


Figure 3. Curve of residual strength vs current peak value(PVC)

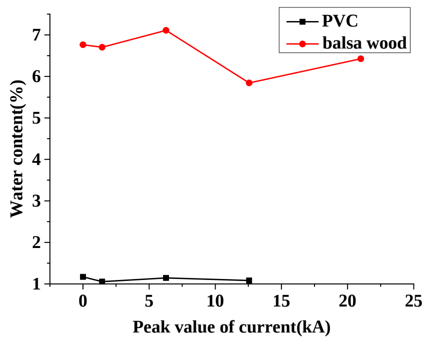


Figure 4. Curve of water content *vs* current peak value after experiments

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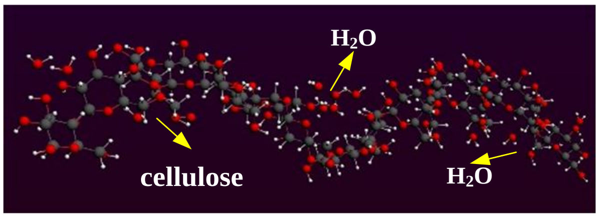

Figure 5. Amorphous cell of cellulose for molecular simulation

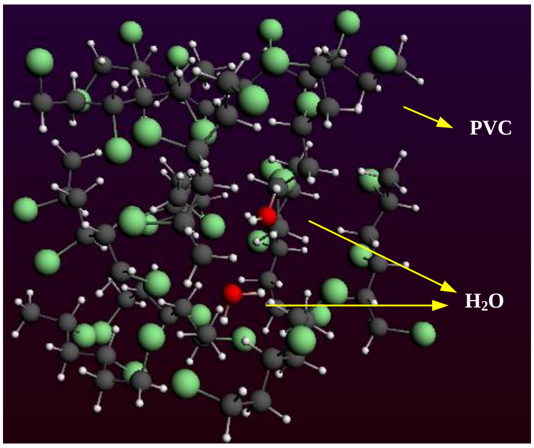

Figure 6. Amorphous cell of PVC for molecular simulation

A. DP

DP of PVC and cellulose, which is a reliable characteristic to indicate the mechanical strength of polymer materials, changes when materials degrade under the thermal effect of large current.

As is shown in the visual results, the molecular chain of cellulose gradually broke down, and its DP decreased with time, but in the aspect of PVC, C-C bond continuously broke and reformed and its DP had no obviously reduction. DP values of the two materials under different temperatures are shown Fig.8 and Fig 9.

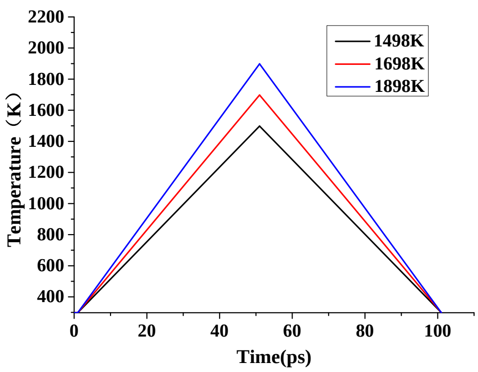

Figure 7. Molecular simulating temperature

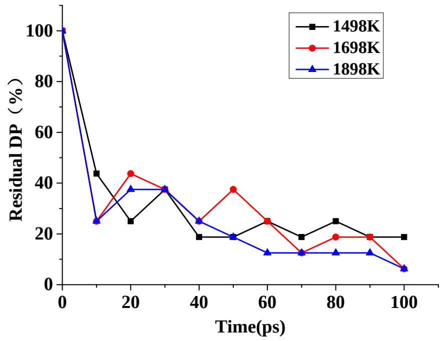

Figure 8 Curve of residual DP of cellulose vs Simulation time

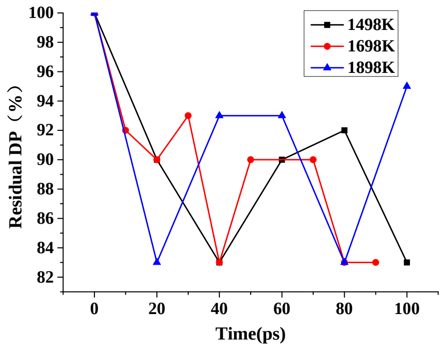

Figure 9. Curve of residual DP of PVC vs simulation time

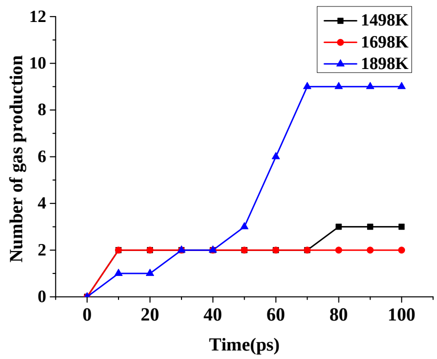

Figure 10. Curve of number of gas products of cellulose vs simulating time

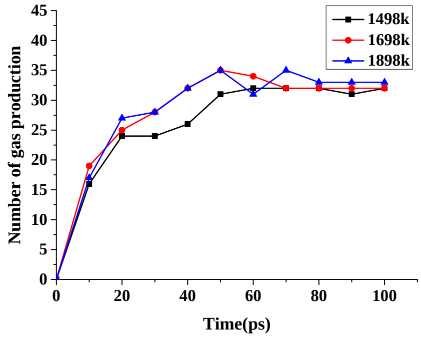

Figure 11. Curve of number of gas products of PVC vs simulating time

B. *Gas Production*

Several kinds of gas generated with the polymer pyrolysis, and they expand when temperature increase sharply, which damages the blade materials to some extent.

The degradation mechanism of cellulose is complicated, and it has many kinds of production with different states, among them, CO, CO_2 , H_2O , H_2, and also some organics with low carbon content will escape to result in gas pressure; As for the PVC, it mainly produces HCland a small amount of alkenes. The statistics of gas production is shown in Fig. 10 and Fig. 11, PVC produces more gas production and it suffers larger stress from gas production expansion.

D. *Water Steam*

There are two kinds of existing forms of water in PVC and cellulose, they are free water and bound water. With much –OH 、H and O included in cellulose, it offered a favorable access to the water in the air to form hydrogen bond with cellulose, which resulted in high water content in balsa wood. Compared with cellulose, the density of hydrogen bond between PVC and water was much lower, the H bond function between H2Oand cellulose and PVC is shown in Fig. 12 and Fig. 13. When temperature increases, both the two kinds of water are easily changed into water steam, which expands to damage the blade materials.

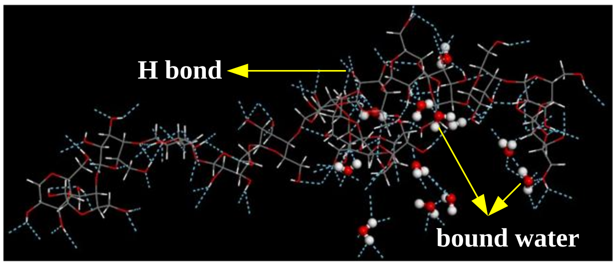

Figure 12 H bond between H_2O and cellulose

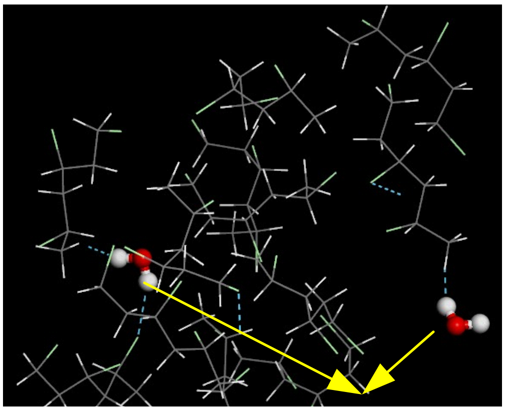

Figure 13. H bond between H_2O and PVC

IV. CONCLUSION

Based on the experimental and simulating results, it can be concluded that:

(1) Lightning induced arc can severely damage the blade materials, and the residual strength of PVC is much less than the balsa wood under the same current value.

(2) Damage characteristics of PVC and cellulose are not the same: PVC is mainly shown as the bigger pore size, which is caused by a large amount of gas production, while the fibers of the cellulose fractured severely, owing to the DP declining and water steam pressure.

(3) The mechanical damage of PVC under lightning induced arc is mainly resulted from the gas expansion pressure consisting of gas production and air in the pore; while the wood damage is owing to the DP reduction, and also the water steam stress.

ACKNOWLEDGMENT

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