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THE AGING EFFECT OF K3B/IM7 IN 80°C WATER

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ABSTRACT

Hygrothermal aging of the laminates of Avimid® K3B/IM7 in 80°C water was studied as a function of immersion time prior to forming microcracks. The factors causing the 80°C water to degradation of the laminates could be the degradation of the matrix toughness, change in residual stresses or interfacial damage between the fiber and matrix. The times to saturation in 80°C water for the laminates and the neat resin are 100 hours and 500 hours. After 500 hours aging of the neat resin in 80°C water, the glass transition temperature was changed less than 1% by DSC test and the weight gain was 1.55% increase. After 500 hours aging, the fracture toughness of the neat resin was decreased about 37% by 3-point bending test. After 100 hours aging of the [+45/0/-45/90]s K3B/IM7 laminates in 80°C water, the weight gain was 0.41% increase. The 80°C water diffusion rate into the neat resin was faster than into the laminates. In 100 hours, the loss of the microcracking toughness of the laminates was 28% of the original toughness by our own microcracking fracture toughness criterion.

초 록

미세균열이 생기기 전 80°C 물속에서 침수시간이 변함에 따른 Avimid® K3B/IM7 복합재의 습기노화 현상에 관하여 연구하였다. 80°C 물속에서 복합재의 강성을 저하시키는 요인으로는 수지 강성의 저하나 잔류응력의 변화 그리고 섬유와 수지 사이의 계면 손상이다. 80°C 물속에서 수지에 습기가 포화되는 시간은 500 시간이며 K3B/IM7 복합재에 습기가 포화되는 시간은 100 시간이다. 80°C 물속에서 수지가 500 시간 가속노화한 후 DSC 시험을 한 결과 T_g는 1% 이내 증가하였으며 무게는 1.55% 증가하였다. 80°C 물속에서 수지의 습기 포화 속도가 복합재의 습기 포화 속도 보다 빨랐다. 500 시간 노화한 후 수지의 파괴인성은 37% 저하하였으며 100 시간 노화한 후 [+45/0/-45/90]s K3B/IM7 복합재의 미세균열 파괴인성은 28% 감소하였다.

Key Words: Hygrothermal Aging, Laminates, Degradation, Micracracking, Fracture Toughness, diffusion.

1. Introduction

This research were to study how the

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hygrothermal aging affects the toughness of the laminates and the neat resin as a function of immersion time prior to forming microcracks.

McDonnel Douglas gave the data that the times to saturation in 80°C water for Avimid® K3B/IM7 laminates and the neat resin are 100 hours and 500 hours. Avimid® K3B neat resin samples were placed in 80°C water for times ranging from 50 hours to 500 hours.

The weight gain and how the aging affected the samples were studied. The factors to degrade the toughness of the laminates could be the degradation of the matrix toughness, change in residual stresses or interfacial damage between the fiber and matrix. The first way to study hygrothermal aging is to study aging of neat resin. The neat resin samples were characterized by three-poing bending tests under plane-strain conditions. The 80°C water aging had an effect on the neat resin K3B. Therefore, matrix-dominated failure analysis for the laminates hygrothermal aging was approached. The laminates layup is [+45/0/-45/90]s. During the experiments to microcrack the 90° ply in the middle of the laminates, there were no microcracks in +45 or -45 plies. The microcracks in the 90° plies were found sufficient to yield good results.

2. Experimental

2.1 The aging of Neat Resin Avimid® K3B in 80°C Water

2.1.1 Materials and Methods

The K3B samples were 6.5 mm thick, 12.6 mm wide and 101.6 mm long. The samples were put in the container which contained water maintained at 80°C Water for 50 hours through 500 hours. The samples were taken out of the oven periodically and the weight gain was measured.

Before the three-point bending tests, the samples were dried out to return to the initial weight. The single edge crack of each sample was made with a band saw first, and then sharped with a fresh razor blade. The cracks were longer than half of the specimen width. The samples were then loaded on a three-point bending fixture in an MTS frame using a cross head rate of 0.01 mm/sec until the sample broke. A critical intensity factor K_{IC} was determined by means of Eq. (1).

$$K_{IC} = y\left(\frac{6}{BW^2} * \frac{PS}{4}\sqrt{a}\right) \qquad (1)$$

where,

$y = 1.93 - 3.07r + 14.53r^2 - 25.11r^3 + 25.8r^4$,

S ; the length of the sample,

$S > 4W$,

P ; applied maximum load to fracture,

$r = \frac{a}{W}$.

Next, the determined K value was plugged into the following plane-strain behavior ASTM requirements, and all the dimensions were checked to see whether the requirements were satisfied.

a ; crack length $> 2.5\left(\frac{K_{IC}}{\sigma_y}\right)^2$, (2)

B ; sample thickness $> 2.5\left(\frac{K_{IC}}{\sigma_y}\right)^2$,

W ; specimen width $> 6.27\left(\frac{K_{IC}}{\sigma_y}\right)^2$,

where K_{IC} is the plane-strain toughness and σ_y is the yield stress.

Under the plane-strain conditions, K_{IC} can

be converted to the G_{IC} (E=3,760 Mpa, ν =0.365).

2.1.2 Results and discussion

Figure 1 shows how much weight the samples gained. The average original weight for two samples was 16.78 g. After 500 hours, the weight went up to 17.04 g which was a 1.55% increase. The weight gain in 100 hours was a 1.06% increase.

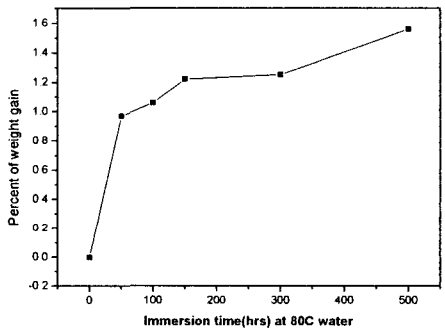

Fig. 1 The percent of weight gain as a function of immersion time at 80°C water for neat resin K3B.

In Fig. 2, the percent of total weight gain was estimated from each of weight gain divided percent of weight gain for 500 hours. In only 50 hours, the percent of total weight gain increased to 62.20%, and then increase slowly. After 500 hours, the percent of total weight gain no longer increased or the sample was almost saturated. The diamonds are the experimental data and the squares are the theoretical data with diffusion coefficient 1.02×10^{-11} m^2/s.

To understand the water diffusion into the neat resin K3B, the diffusion coefficient D, whose magnitude is indicative of the rate at which atoms diffuse, was introduced, Fick's second law was used :

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2} \qquad (3)$$

where, C is concentration in terms of weight % or mass of diffusing species per unit volume (kg/m^3). D is called the diffusion coefficient which is expressed in square meters per second (m^2/s). t is time (sec).

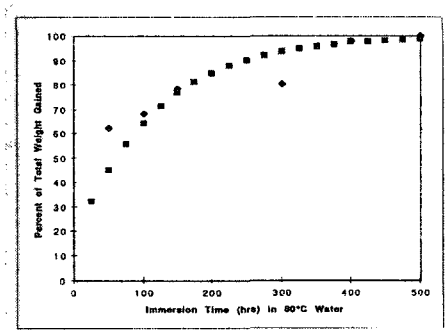

Fig. 2 The percent of total weight gain as a function of immersion time at 80C water for neat resin K3B.

Let us consider the model as the slab whose boundary conditions are :

for t=0, C=0 at $0 \leq x \leq B$,

for t>0, $C=C_{sat}$ (saturated concent.) at x=0

$C=C_{sat}$ at x=B (thickness).

Applying the boundary conditions to Fick's second law yields following solution [1] :

$$C(x,t) = C_{sat} + \frac{2}{B}\sum_{m=1}^{\infty} e^{-D\beta_m^2 t}\frac{1}{\beta_m} sin\beta_m x \qquad (4)$$

$$(C_{sat} cosm\pi - C_{sat})$$

where, $C(x,t)$ represents the concentration at length x after time t, and $\beta_m = \frac{m\pi}{B}$.

Taking a few of the terms in Eq. (4) and

calculating the average value of the diffusion coefficients inside the body, the results were obtained (refer to Fig. 1).

Figure 3 shows the changes in fracture toughness as a function of immersion time. The results present the average fracture toughness for two replicate experiments. The average toughness shows a gradual loss as the aging time increases.

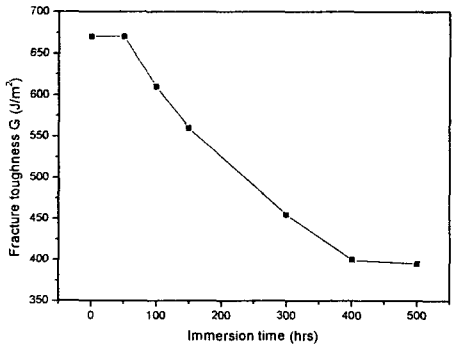

Fig. 3 The fracture toughness as a function of aging time in 80C water for resin K3B.

2.2 The aging of Avimid® K3B/IM7 in 80°C Water

Figure 4 describes the percent of total weight gain as a function of immersion time at 80°C water for Avimid® K3B/IM7. In 60 hours, the percent of total weight gain increased to about 95%, and then increased slowly. The diamonds are the experimental data and the squares are the theoretical data with diffusion coefficient 8.1×10^{-13} m^2/s.

Figure 5 shows how the 80°C water has changed the microcracking toughness of K3B/IM7 laminates as a function of aging time. The unaged microcracking toughness was 1460 J/m^2. The 30 hours aging changed the microcracking toughness to 1380 J/m^2 which corresponded to a 5.5% decrease of the original toughness. In 100 hours, the loss of the microcracking toughness was 28% of the original toughness.

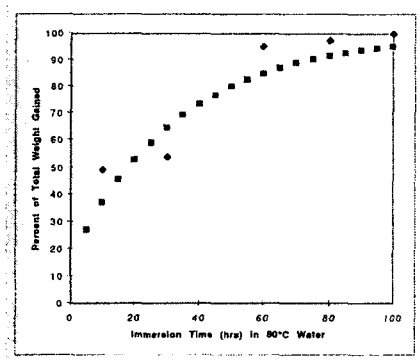

Fig. 4 The percent of total weight gain for the laminates as a function of immersion time at 80°C water.

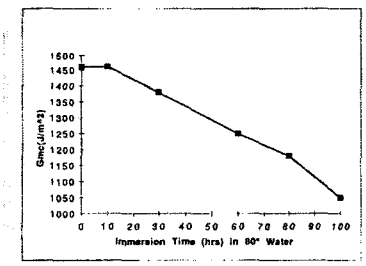

Fig. 5 The microcracking fracture toughness changes as a function of immersion time in the laminates.

참 고 문 헌

1. Ozisic, M. Necati (1980), Heat Conduction, New York, John Wiley & Sons Inc.
2. Nairn, J. A. (1989), "The Strain Energy Release Rate of Composite Microcracking: A Variatonal Approach," Journal of Composite Materials 23, 1106