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Moisture Concentration Effect on Reliability in Graphite/Epoxy Plates under Environmental Conditions

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Abstract: The deterioration of composite materials due to moisture and environmental attacks is one of the most critical phenomena in lifetime management of structures. In this research, the effects of temperature and moisture on polymer composite plates are studied. On the basis of Fick's law, the analysis of hygrothermal effects allows us to determine the evolution of water concentration through graphite/epoxy plates thickness. A transient hygrothermal analysis is performed to show the environmental effects on composite materials deterioration during absorption process. This deterministic modelling is followed by a probabilistic study allowing to analyse the development of uncertainties within the model and to consider the role of water concentration on the composite material life span. The study shows also the importance of reliability analysis in composite materials design to achieve a robust design.

Key words: Composite materials, hygrothermal behaviour, diffusion, reliability analysis

INTRODUCTION

Under cyclic environmental conditions, temperature and moisture produce a considerable stresses which can probably cause the deterioration of the polymeric matrix composites that's due an important increase in the concentration of moisture and a variation in the temperature.

The composite material considered in this study is the graphite/epoxy, which used more particularly in aeronautical and space structures, that are more exposed to the heating accidental functional calculus makes or environmental which can contribute in an important way in the degradation of these materials and thus affect the integrity of the composite structures that's because of the fast degradation of the mechanical properties (longitudinal and transverse stresses, modulus of elasticity... etc.) (Griffis *et al.*, 1981; Colling and Mead, 1988).

Let us note that all the assumptions presented in our article for the study of the evolution of the non-uniformed concentration attracted research like those presented by Springer (Adda *et al.*, 1998, 2000; Verchery, 1990) for the prediction the moisture diffusion under cyclic environmental conditions. We present thereafter, an analytical method which also investigates the moisture saturation as well as the time of saturation. Moreover, a study of the environmental conditions effects are based on the values of saturation and the decomposition of the graphite/epoxy exposed to the hygrothermal conditions is proposed.

For our study, the environmental loading is supposed to be cyclic and the main cycle is specified by changing the temperature and moisture.

The analysis of the structural durability must provide the element which makes it possible to investigate its capacity to fulfil the functions of the schedule conditions over the defined duration of time, when it is subjected to a mechanical loads in interaction with the environment.

The problems are thus, to obtain in a reasonable time, sufficient information to find later on the moisture concentration evolution and the prediction of the reliability of the composite material plates under climatic conditions.

MODELLING PROBLEM

Fick's model for water absorption: For the considered plate,the water diffusion within the composite plate is well described by the second law of Fick, where the solution is determined by a numerical incremental procedure based on a step-by-step time integration

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(Hinghsmith *et al.*, 1984). As, for thin plates, the diffusion is carried out according to only one direction (i.e., through the plate thickness), the second law of Fick takes the form:

$$\frac{\partial C}{\partial t} = D_x \frac{\partial^2 C}{\partial x^2} \quad (1)$$

Where C is the moisture concentration, D_x is the plate diffusivity in the x-direction and t is the time. In our case, this equation is subjected to the boundary conditions:

$$C\ (x, 0) = 0 \text{ for } 0 \le x \le h \quad (2)$$

$$C(0, t) = c_1 \text{ et } C\ (h, t) = c_2 \text{ for } t > 0 \quad (3)$$

Crank (1983) presented a mathematical solution for Eq. 1 under different geometrical and boundary conditions. In a thin plate with thickness h and initial concentration C_i, where the surfaces are kept under uniform concentration C_8 (water concentration at saturation (infinite time)), the concentration is given by:

$$\frac{C - C_i}{C_\infty - C_i} = 1 - \frac{4}{\pi}\sum_{n=0}^{\infty} \frac{(-1)^n}{2n+1}\cos\frac{(2n+1)\pi x}{h} \exp\left[-\frac{D_x (2n+1)^2 \pi^2 t}{h^2}\right] \quad (4)$$

Where:

$$D = DA1.\ e^{-DA2/T} \quad (5)$$

$$C_\infty = CC1.\ H^{CC2} \quad (6)$$

Where H is the relative humidity (%), DA1 is the permeability index (mm^2/S), DA2 is the specific constant of the material (°K), CC1 and CC2 are dimensionless material constants.

Water absorption in studied plates: A plate made of graphite/epoxy T300/5208 was investigated under a cyclic environment actions of temperature and moisture, which applied on both faces (Fig. 1). Three plates thickness have been considered: 4.8, 8.8 and 13.8 mm. The characteristics of the T300/5208 are given in Table 1 (Tsai, 1998; Loos and Springer, 1981).

The studied plates are subjected to temperature and relative humidity, according to the cycles illustrated in Fig. 2. For a period of 144 h, the temperature varies from 27°C to 65°C, up to 142°C limit, while the relative humidity varies between 14 to 82%. These cycles are corresponded to a flight testing, as described by Springer (1981). This plane test simulates temperature and moisture variations during 123 h in normal atmospheric conditions, followed by 11 h of flight, and finally 10 h of normal atmospheric conditions. In the test, the ambient relative humidity is increasing while temperature is decreased, except the situation during the flight where moisture becomes zero. It can also be seen that the high relative humidity is limited by 82%, except during the flight time. Also, the studied plates are exposed to 2000 cycles, 144 h in each one, as described in Fig. 2; which equivalent to nearly 33 years. Then the diffusion analysis aims to compute the moisture concentration through the plate thickness, as a function of time. This can be carried out by numerical integration of Fick's laws for water absorption in composite plates, as described in the above section (Shen and Springer, 1976; Shirrell, 1978).

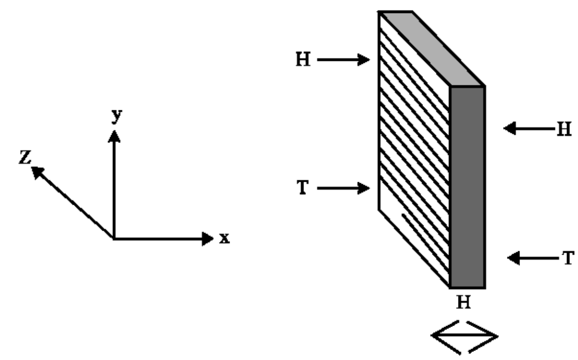

Fig. 1: Plate subjected to temperature and moisture in the x-axis direction

Table 1: Characteristics of the T300/5208 material

□ (Kg m^{-1} 3)	C_∞	DA1 (mm^2 S^{-1})	DA2 (°K)	CC1	CC2
1600	1.23	0.57	4993	0.015	1

For the three thicknesses at 27°C, Fig. 3 shows the moisture concentration inside the plate at different loading periods. It can be observed that for the studied material, the moisture concentration do not exceed 0.71% whatever the ageing time.

Under 27°C, we noticed that the necessary time to arrive to the balance is very long for h = 4.8 mm. The profile with balance is obtained after approximately 600 cycles. This result confirms the need for using a method of accelerated calculation.

After 600 cycles, we could also notice that the water concentration does not exceed 0.71%, this value is much, lower than the maximum concentration which is equal to 1.23 %.

More in the case of 4.8 mm, the Fig. 3 shows that moisture concentration is more important than 8.8 mm and 13.8 mm. Thus, we develop the reliability analysis by this thickness considering.

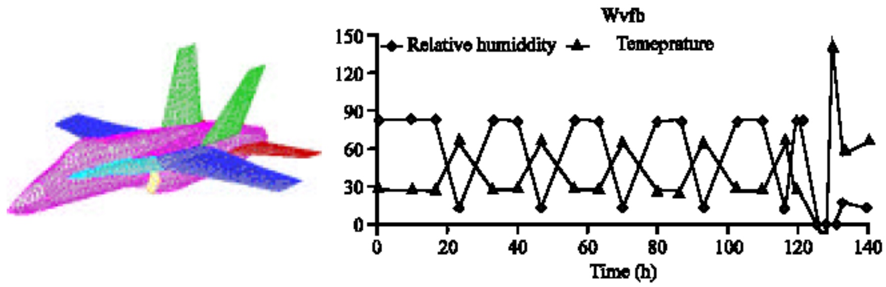

Fig. 2 : Applied environmental temperature and relative humidity cycles before and after flight

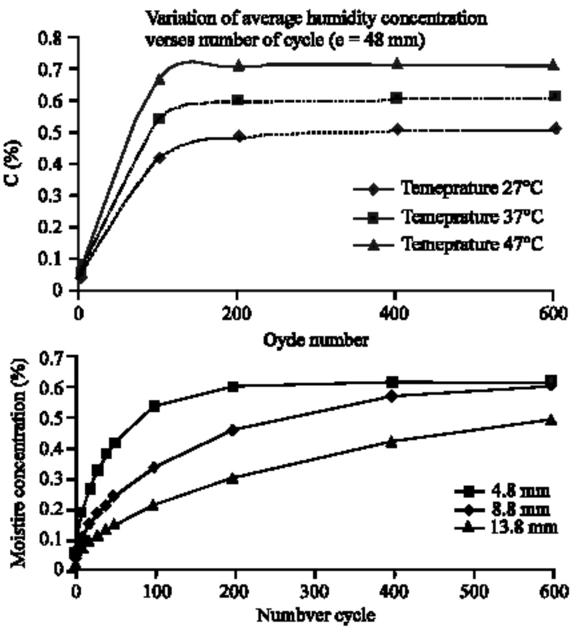

Fig. 3: Moisture concentration as a function of cycles

Development of model uncertainties: In order to study the scatter of the moisture concentration, the Graphite/Epoxy plates are subjected to 2000 cycles of 144 h, as illustrated in Fig. 1. Although that saturation is observed at 600 cycles, the random sampling may lead to much larger saturation times, as illustrated in Fig. 4. For this reason, 2000 cycles have been chosen in order to be sure that saturation is reached in all the simulated configurations. The thermal conductivity is set to 402.2 W/m°K and the parameters are taken as in Table 1. The distribution of moisture concentration is determined by performing Monte Carlo simulations on the model parameters. For each random sample, the incremental diffusion model is applied in order to determine the response in terms of moisture concentration, Fig. 4 shows an example of few random samples. The input model uncertainties are

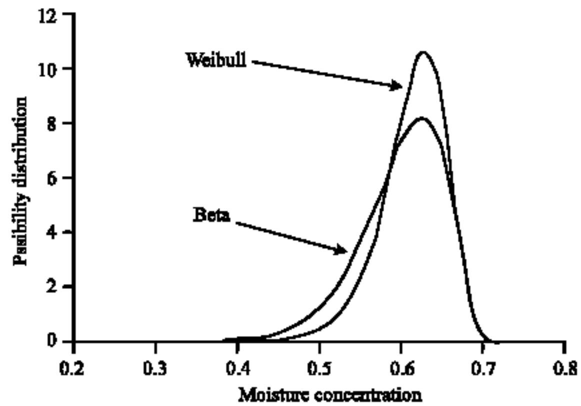

Fig. 4: Comparison of moisture models for plates with thickness 4.8 and 13.8 mm

Table 2: Distribution parameters for moisture distribution fitting

Distribution	Thickness	Parameters	Kolmogorov-Smironov test
Weibull	4.8	□ = 8, □ = 0.63	0.068

considered by assuming normally distributed random variables with a given Coefficient Of Variation (COV). In this study, the randomness is considered for the parameters DA1 and DA2, as well as for the plate thickness. For each configuration, one thousand random simulations have been carried out, leading to one thousand realisations of the moisture concentration. The statistical analysis of the response allows us to determine the influence of each parameter on the concentration scatter.

For plates with thickness of 4.8mm, the Monte Carlo simulation is carried out according to the coefficients of variation indicated in Table 2. The observation of the moisture concentration parameters shows that the thickness dispersion and of DA1 parameter have no significant effect on the mean moisture concentration and very low effect on its standard deviation. Hence, these parameters are not critical for material characterization.

Within the considered ranges, small increase of the coefficients of variation of DA1 seems to decrease slightly the dispersion of the moisture concentration; this can be explained by the random compensation between DA1 and DA2 samplings.

According to the above results, it can be recommended to model the moisture distribution by an extreme value distribution. By testing several types of distributions, we have found that Weibull and Beta distributions are very suitable to represent the moisture scatter in graphite/epoxy plates. Table 2 gives the distribution parameters for the three considered thickness. Although the beta distribution fits less the Kolmogorov-Smirnov test, it gives a better representation of the lower distribution tail. However, it has the inconvenience of truncation at the upper bound.

CONCLUSION

The whole results obtained are satisfactory, because the water concentrations in the studied plates do not exceed 0.71%, this value much more less than the value of the maximum concentration C_8. Also it is noted that the lifespan of using graphite/epoxy material can go up to 33 years of service. This lifespan is increasingly claimed in the applications of high performances and more particularly in the aeronautics.

It can be concluded that the composite materials with polymer matrix have important properties compared to traditional materials. They bring many functional advantages: Lightness, mechanical resistance, chemical and freedom of forming. Also it is possible to increase the lifespan of certain equipment that is due to their properties which contribute to the reinforcement of safety. However, to put forward these properties and to achieve its goals, the industry of composite materials must integrate the environmental component of the durable development in its strategy of growth.

REFERENCES

Adda-Bedia, E., W.S. Hahn, G. Verchery, 1998. Simplified methods for prediction of moisture diffusion in polymer matrix composites with cyclic environmental conditions. Int. J. Polym. Compos., 6: 189-203.

Colling, T.A. and D.L. Mead, 1988. Effect of Hight Temperature Spikes on a Carbone Fiber-Reinforced Epoxy Laminate. Composites, 19: 61-88.

Crank, 1983. The mathematics of diffusion. Oxford University Press, (2nd Edn.), Reprinted.

Griffis, C.A., R.A. Masumura, C.I. Chang, 1981. Thermal Response of Graphite/Epoxy Composite Subjected to Rapid Heating. J. Compos.Mater., 15: 427-442.

Hinghsmith, A.L., W.W. Stinchcomb, K.L. Reifsnider, 1984. Effect of Fatigue induced Defects in Composite Response of Composite Laminates. Effects Of Defects in Composites Materials, ASTM STP 836, Am. Soc. Testing Mater., pp: 194-216.

Loos, A.C., G.S. Springer, 1981. Moisture absorption of Graphite/Epoxy composites immersed in liquid an humid air. Environ. Effects on Compos. Mater., pp: 34-50.

Shen, C., G.S. Springer, 1976. Moisture absorption and desorption of composite materials. J. Compos. Mater., pp: 10:12.

Shirrell, C.D., 1978. Diffusion of Water Vapor in Graphite/Epoxy Composites. Advanced Composite Materials-Environmental Effects, ASTM, STP 658, (Ed.), Vinson, pp: 21-42.

Springer, G., 1981. Numerical procedures for the solutions of one-dimensional Fickian diffusion problems. Environmental effects on composite materials, Technomic Publishing Co. Westport, CT06880, USA., pp: 166-199.

Tsai, W.S., 1988. Composite Design. Think Composites. (4th Edn.), OH, USA/ Dayton.

Verchery, G., 1990. Designing with anisotropy. In: Hamelin, P. Verchery G. (Eds.), Textile composite in building construction, Part 3, Mechanical behaviour, design and application. Paris: Pluralis, pp: 29-42.