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EFFECTS OF WET/HOT SPECTRUM AGING ON STRENGTH OF COMPOSITE LAMINATES

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ABSTRACT

Absorbed moisture and high temperatures soften the resin matrix composite materials. This affects composite strength, failure modes and failure strain level. In consequence, design and certification of composite airplane structures require the consideration effects of the hygrothermal history expected in service.

Tension tests of undamaged laminates and laminates with a central hole, CAI tests were performed on BMI composite panels after exposure to accelerated wet/hot spectrum over full service life in order to investigate the influence of wet/hot spectrum aging on undamaged and damaged laminates strength and stiffness.

The impact event of 15 J energy was induced before aging, the representative damaged state was determined by C-scan. The results show that wet/hot aging causes seriously strength drop, especially CAI strength. The survivability of CAI strength and failure strain after aged was only 79.1% and 86.2%, respectively. This is due to the synthetic effects material degradation and interior stress repeated action. Impact damage area after aged grew a little.

1. INTRODUCTION

Hygrothermal aging effects for fiber reinforced composite are a gradually degradation process caused by combined action of moisture uptake, temperature and stress. Degenerative mechanism is acted upon fiber, interface, and matrix, and causes physical and chemical reaction. During moisture absorption process interior in composite will produce swelling stress, the more swelling stress in wet structure under thermal spiking will be produced due to quickly moisture desorption of structure out layers. When this interior stress repeatedly acts and reaches certain magnitude, stress crack will rise, and consequently crazing, which affect the moisture re-absorption and re-desorption rates. Finally, macrocrack is formed. Damaged composite laminate under long duration hygrothermal environment would degrade and may cause damage growth, finally strength and stiffness would decline.

The military aircraft composite structures will experience the effects of hygrothermal environment on the ground and elevated temperature caused by aerodynamic heating. Therefore, it is important to investigate the effects of long-term hygrothermal and thermal load environments on behaviors of composite structure for increasing aircraft composite application. An important design criterion for using composite materials in primary structure is the Compression After Impact (CAI) strength. As a basis for a complete durability analysis we need a good understanding the residual structural integrity of composites system after an imposed life time under a complex mechanical loading history in interaction with environmental variations.

In addition to study the effects of 4 times service life wet/hot spectrum aging on absorbed moisture property and tensile strength of bared composite laminates, this study focused on the effects of wet/hot spectrum aging on tensile strength of the laminate with a open hole and CAI strength.

Hygrothermal aging generally causes a change in the material properties of a composite, brought about by chemical reaction occurring at elevated temperature. The rate of change in the material is determined by many factors, including the chemical composition of the constituent materials, aging temperature, fiber volume fraction, and ply orientation of the laminate surface. For a given composite, the reaction is controlled by the temperature, surface area, and duration of the exposure to air.

In addition, thermoset matrix materials will experience continued post-cure linking of the polymer chains when held at elevated temperature. This additional linking will cause the matrix to become more stiff and brittle. Increased stiffness will raise the ultimate strength properties, while the increased brittleness will reduce toughness. The resulting effect on fracture properties is a combination of these two influences.

2. SPECIMEN AND EXPERIMENTAL PREPARATION

2.1 Specimen

T300/5405 was selected as the tested material. The volume fraction of fiber is 60%. The lay-up of specimen is the same with the integral tank of composite wing, $\left[45/0/-45/0/45/90/-45/0/45/0/\overline{-45}\right]_{S.}$ The type and geometry is shown in Table 1.

2.2 Wet/Hot and Accelerated Spectrum

The aircraft in service may be affected by a variety of environmental factors, such as temperature, humidity, lightening strike, sand, hail, rain and snow, ultraviolet light, and atmosphere pollution etc. overall environments, and fuel, skydrol, cleaning solvent etc. local environments. Among many factors, the effects of temperature and humidity on composite are most serious.

Generally, the service life of military aircraft is about 3000-4000 flight hours and calendar life is about 20-25 years.

The accelerated wet/hot spectrum is shown in Fig. 1. The thermal load spectrum in 4 hours represents the synthetic response of 100 flight hours, 60℃/95%RH accelerated hyrgrothermal impregnation in 20 hours represent environmental effect on the ground in one year.

2.3 Introduction of Impact Damage

Determined impact energy is 15 J for the designed layer specimen based on selectivity criterion. Before aged the impact was induced from impactor with a 12.7 mm diameter hemispherical head.

3. TEST PROCEDURE AND PROGRAM

3.1 Specimen Preparation

The steps of specimen preparation were

1) Classifying and numerating for specimens,

2) Precision measurement for width, thickness and hole diameter,
3) Impact damage of 15 J is introduced at the center of laminate and damage state was inspected using C-scan,
4) All specimens was dried upto engineering dry according to aeronautical industry standard and weighted for each specimen and recorded as M_0.

3.2 Test Procedure and Program

The tests were performed in hygrothermal chamber. The temperature rate of raising or reducing was not less 6 ℃/min, the accuracy of controlled temperature was ±3 ℃. The test step were

1) Tested specimens were per-impregnated under 60/95%RH condition about 10 days,
2) Aging test was performed according wet/hot accelerated spectrum upto 4 times life, and specimen was weighted during regular intervals,
3) Damage state was inspected by C-scan,
4) Strain gage was pasted on the specimen,
5) Tension and compression test was performed for Ⅰ,Ⅱand Ⅲ type specimen.

4. TEST RESULTS AND DISCUSSIONS

4.1 Aging Moisture Absorption Behavior of Specimen

The variation of moisture content is shown in Fig. 2.

4.2 Tension Test Result of Type Ⅰ Specimen

Under nature dry condition:

E=54.1 GP_a, μ_{12}=0.526, P_f =40.39 kN, ε_f=11557 $\mu\varepsilon$, δ_f =6.13 mm

After accelerated aged:

E=53.1 GP_a, μ_{12}=0.529, P_f =37.32 kN, ε_f=10011 $\mu\varepsilon$, δ_f =4.77 mm

Then tension strength, failure strain and elastic module reduced 7.6%, 6.3% and 1.3% respectively.

4.3 Test Result of Laminate with a Center Hole

No damage was inspected at hole side after aged.

Under nature dry condition:

E=56.15 GP_a, P_f =33.50 kN, ε_f =6225 $\mu\varepsilon$, δ_f =3.49 mm

After accelerated aged:

E=54.02 GP_a, P_f =28.94 kN, ε_f =5579 $\mu\varepsilon$ δ_f =4.10 mm

Then tension strength, failure strain and elastic module reduced 13.6%, 10.4% and 3.8% respectively.

4.4 Effect of wet/hot Spectrum Aging on CAI

Under nature dry condition for undamaged laminate:

E=55.00 GP_a, P_f =78.05 kN, ε_f =5591 $\mu\varepsilon$

After accelerated aged:

E=53.13 GP_a, P_f =72.85 kN, ε_f =5752 $\mu\varepsilon$

Then compression strength, failure strain and elastic module reduced 6.6%, 4.0% and 3.8% respectively. But under nature dry condition for damaged laminate:

E=47.96 GP_a, P_f =59.20 kN, ε_f =4392 $\mu\varepsilon$

After accelerated aged:

E=46.20 GP_a, P_f =42.91 kN, ε_f =3988 $\mu\varepsilon$

Then CAI strength, failure strain and elastic module reduced 20.9%, 13.8.0% and 3.5% respectively. The test results are show in Fig. 3and wet/hot aging caused seriously strength drop, especially CAI strength. The survivability of CAI and failure strain after aged was only 79.1% and 86.2% respectively. This is due to the results of material degradation and interior stress repeated actions. Impact damage area after aged grew a little.

5. CONCLUSIONS

The following conclusions could be drawn based on the wet/hot accelerated aging test results:

1) Influence magnitude of aging on undamaged laminates behavior is within 10%,
2) Influence magnitude of aged on behavior of laminates with a hole is within15%,
3) Influence magnitude of aged on CAI strength is within20%.
4) Moisture content of bared specimen during wet/hot aged appears ring and falling trend,
5) Accelerated aged test is useful shortcut to investigate aging response.

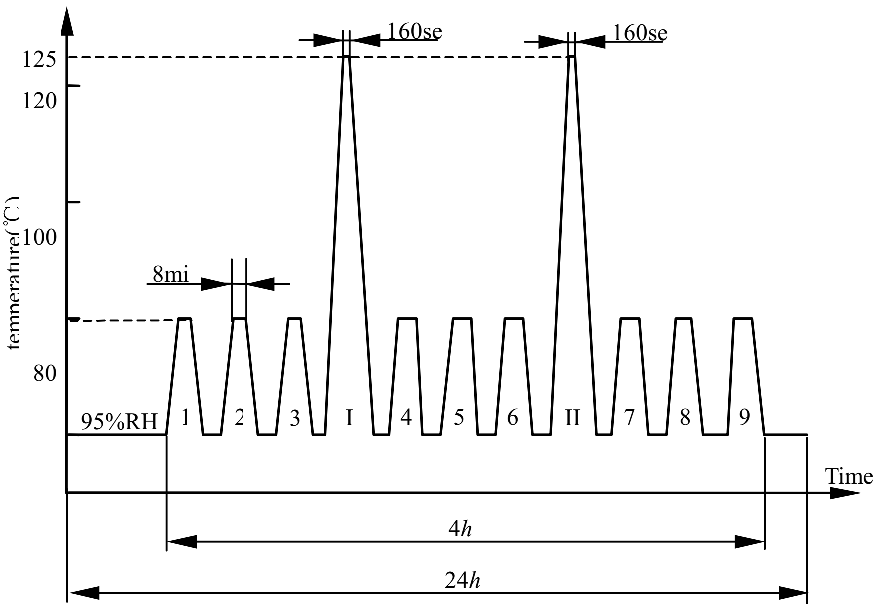

Fig.1 Accelerated wet/hot aged spectrum

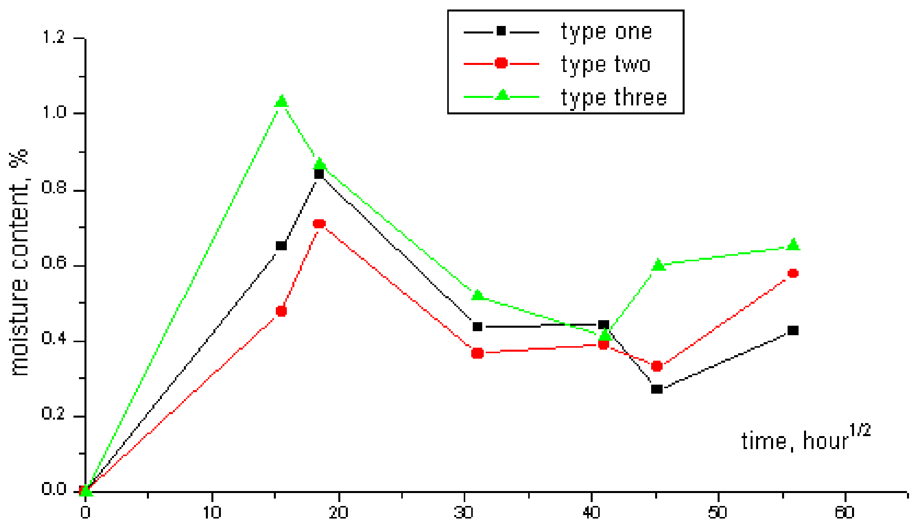

Fig.2 Variations of moisture content

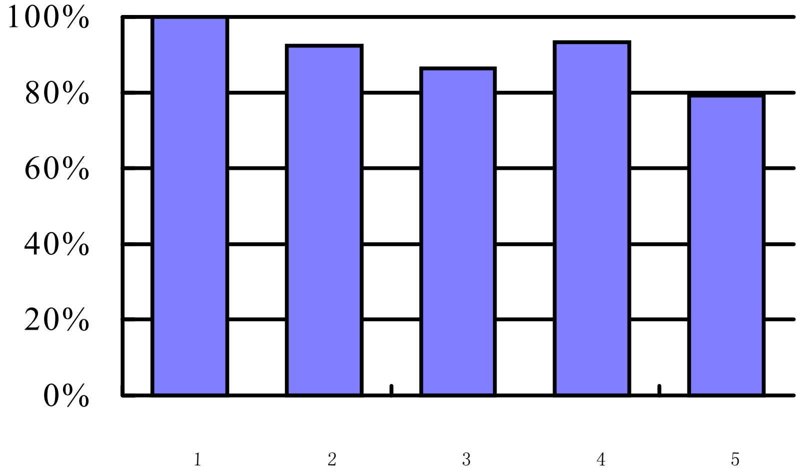

Fig. 3(A) Strength survivability of aged

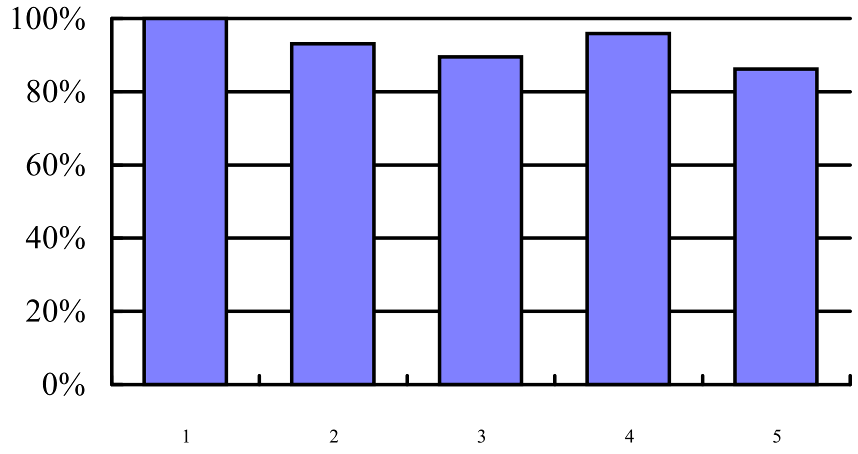

Fig. 3(B) Failure strain survivability of aged

Note: 1) the value at Room Temperature Dry; 2) tension after aged; 3) tension with a center hole after aged; 4) undamaged compression after aged; 5) CAI

Table 1 Type and size of specimen

Type	I	II	III
Item	Tension	Tension with a hole	Compression
Size(mm×mm×mm)	230×25×2.5	230×38×2.5	150×100×2.5
Number	20	20	10
Numeration	101～120	201～220	301～310

Hole diameter ϕ=6.35mm