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Graphite/Epoxy $(0^\circ/90^\circ)_{2S}$ 적층판에 있어서의 피로거동에 대한 하중과 Creep의 영향

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Effect of Load Level and Creep Interruption on Fatigue Behavior for Graphite/Epoxy $(0^\circ/90^\circ)_{2S}$ Laminate

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요 약 : 본 연구에서는 cross-ply carbon/epoxy laminate, T300/5208, $(0^\circ/90^\circ)_{2S}$의 fatigue와 fatigue-creep 하에서의 거동을 살펴 보았다. Replication technique을 사용하여, 하중이 비교적 낮은 경우의 초기상태에서, 매트릭스의 축방향에 수직인 crack들의 density 변화를 측정한 결과, fatigue-creep 에서의 crack density가 fatigue의 경우보다 높았다. 이는 fatigue-creep 에서의 평균 하중치가 fatigue의 경우보다 높음에 기인한다. 한편, 가해진 하중이 비교적 큰 경우, 즉, 매트릭스의 손상이 심한 경우에 fatigue-creep의 축방향 변형은 fatigue의 경우보다 약간 작았다. 이는 creep period 하에서의 fiber-stiffening 현상에 기인하다고 여겨진다. 그러나, 하중이 매우 높은 경우에 creep은 fatigue-life에 영향을 미치지 않았다. 이는 보강섬유와 매트릭스의 damage가 동시에 최종 파괴에 영향을 미치기 때문인 것으로 사료된다.

Abstract : This study concentrates on the mechanical behavior and the matrix cracking development in the early fatigue and fatigue-creep life in cross-ply graphite/ epoxy laminates T300/5208, $(0^\circ/90^\circ)_{2S}$. The replication technique was used to observe the transversal crack density variation for several loading levels. The life time was measured only for the high load level. At this level, the creep has no effect on the number of cycles to failure. The longitudinal behavior was slightly influeneced by the creep interruption. This fact can be attributed to the fibre dominated longitudinal behavior in this system. And the transversal crack density in fatigue-creep is higher than that in fatigue loading. It comes from the higher load level in fatigue-creep than that in fatigue.

INTRODUCTION

To define the objectives of this work, it is useful to firstly refer the previous works[1~6] in fatigue loadings. During fatigue loading of a graphite/epoxy cross-ply laminates, there are several components of damage ; fiber breakage, matrix cracking, interphase delamination, decohesion between matrix and fibre, splitting and so forth.

In general, there are two tendencies in the damage development approaches with the fatigue loading. The first is the observation of matrix cracking development[7] and its effect for the stiffness reduction[6] and for the fiber breakage.[8]

The second is to define several damage steps in fatigue loading with the stiffness reduction as a damage analogue[2,3] in the middle load level. In this stiffness reduction procedure, there are three different stages.[3] At the first stage, the matrix cracking is important. The matrix ductility[2] and the load level[1] influence this matrix induced damage. And it has not been well investigated.

In this work, the various loading levels in fatigue were used to find the load level effects for the stiffness reduction in early fatigue life. The edge replicas were taken to observe microscopically the variation of the transversal crack densities. To understand the time dependent evolution of material properties, the fatigue-creep solicitation was used to observe the mechanical behavior and to compare the matrix cracking in fatigue and in fatigue-creep loadings.

EXPERIMENTAL

T300/5208 graphite/epoxy $(0^\circ/90^\circ)_{2s}$ ($V_f=0.67$) was supplied by ONERA of France. The stacking sequence is 0°/90°/0°/90°/90°/0°/90°/0°. Straight sided specimens with 270 mm long, 20 mm wide and 1 mm thick were prepared and its gage length was 135 mm. The glass/epoxy tabs were used. The side edges of the specimens were ground with polishing powders. The fatigue loading (f=2 Hz, triangular form, R=0.1) was applied with the constant maximum loading levels, 50%, 60%, 70%, 80% and 90% of Sult (Tensile Strength), by the hydraulic testing machine, Instron. The strain gauges were used to detect the deformations of the specimens. The life time was measured for 90% of Sult. For other loading levels the measurements were done within certain cycles because of the strain gage breakage.

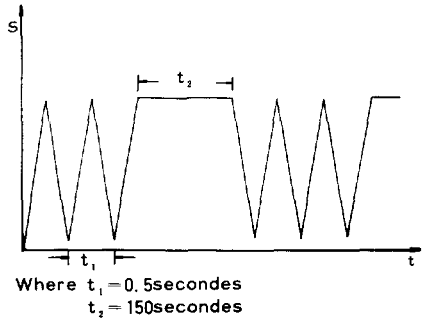

Fig. 1. Interruption of fatigue by creep.

For the fatigue-creep solicitation, the fatigue cycles were regularly interrupted by the creep solicitation (see Fig. 1). Computer control technique for the Instron was used to generate this type of loading history. For the loading levels of 50%, 60%, 70%, 80% of Sult, the fatigue loading was interrupted every 300 cycles. For 90% of Sult loading level, the fatigue loading was interrupted every 30 cycles. The creep period was always 150 seconds. Replications were regularly taken by using the acetone swollen cellulose acetate at the specimen edge in fatigue and fatigue-creep solicitation. And then they were observed microscopically.

RESULTS AND DISCUSSTION

For the cross-ply laminates, the mechanical behavior is dominated by the fibers. The carbon fibers are very resistant to the fatigue loading. If the load level is very low, there would be no degradation of the mechanical properties even after one or two million cycles. In this structure, the matrix cracking could represent the easily observable damage development. The load level, where the first matrix cracking arrives in the center 90°/90°ply, is chosen to the minimum load level. It's near the 50% of the tensile strength (Sult).[9] Below this stress level one cannot find the apparent damage with repeated cycles.

The triangular form of fatigue cycle is chosen to correlate the stress-controlled monotonic tensile test and the stress-controlled fatigue test for the further. For these reasons the sinusoidal and the rectangular forms are discarded. The longitudinal deformations are shown in Fig. 2 and 3. At 50% of Sult, there is practically no stiffness reduction. The increasing transversal cracks by the repeated cycles do not alter the longitudinal behavior. It's the same phenomenon as what was observed in the monotonic tensile test.[9] For 60% and 70% of Sult, the longitudinal strain increases a little at the starting few hundred cycles. And then it's maintained about the same for 10,000~15,000 cycles. A little strain increase at the beginning is due to the fracture of the part of mis-aligned fibers and the matrix crackings by the fatigue loading: After this step, the another part of mis-aligned fibers are supposed to rearrange and give an additional load bearing ability. After 10,000~15,000 cycles, the deformations increase again. It's due to the incremental slow fiber breakages induced by the severe matrix crackings. The stress concentrated in the adjacent matrix crack tips bring about the shear mode fiber rupture. For 80% and 90% of Sult, the deformation increases nearly straight until the final repture. It means that the fiber breakage continuously occurs. From these facts one can conclude that the load level alternates the starting damage point and imposes the different fatigue behavior.

The fatigue-creep solicitation is applied to see the creep interruption effect for the behavior. Fig. 4 and 5 show the longitudinal deformations in this complex loading. They show the similarity with each other in fatigue. It comes

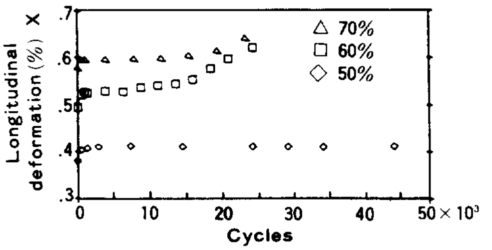

Fig. 2. Variation of longitudinal deformation in fatigue loading.
△, 70% ; □, 60% ; ◇, 50%

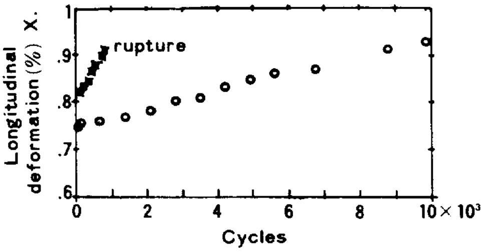

Fig. 3. Variation of longitudinal deformation in fatigue loading. ⊗ : 90%, ○ : 80%.

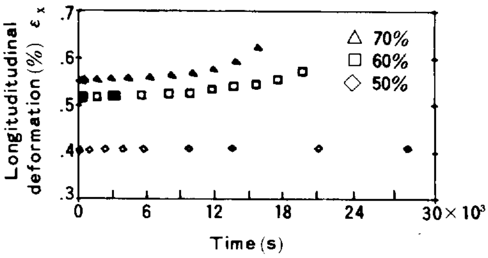

Fig. 4. Variation of longitudinal deformation in fatigue-creep.
△, 70% ; □, 60% ; ◇, 50%

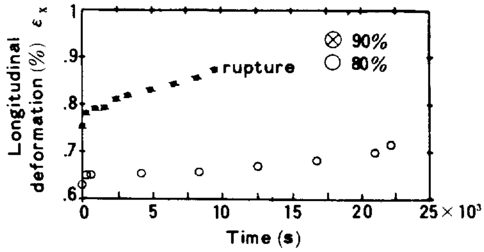

Fig. 5. Variation of longitudinal deformation in fatigue-creep.

Table 1. Comparison of the Life—Time

Fatigue(Cycles)	412	801	853	1989
Fatigue(Cycles)	120	1110	1140	1230
Creep(Sec.)	477	5400	5550	6150

from the fiber dominated characteristics in this system. But the sudden increase of deformation at the beginning is more apparent than that in fatigue. The creep load level is higher than the mean fatigue load level. It would be from the mean load level difference.

For 50%, 60% and 70% of Sult, the deformations in fatigue-creep are slightly greater than them in fatigue. It would be due to more pronounced matrix crackings and the higher mean load level. For 80% and 90% of Sult, the deformations in fatigue-creep are slightly lower than them in fatigue. We suppose that the creep load retards the fiber breakage process by giving the times for fiber rearrangement and stiffening. It requires more detailed data.

To know the creep effects for life, the number of fatigue cycles at the fatigue and the fatigue-creep is measured. These results are summarized in Table 1. Although the creep period is ten times long than fatigu period, the results show that there are no significant differences in the number of fatigue cycles.

The transversal crack density variation in these two loading systems was observed by the replication technics. The replicas were taken at the mean load level for fatigue and at the maximum load level, creep period, for fatigue-creep. The results are shown in Fig. 7 and 8. The crack density in fatigue-creep is higher than that in fatigue. It comes from the higher mean load level. In this case the crack density in center ply is higher than that in outer plies. The first crack appears in the center ply. It causes the more pronounced crack development in the center ply at the early stage of fatigue. The cracks concentrate at the failed ply. Because a samll additional stress can easily make the subsequent cracks in this ply.

We have also analysed the transversal strain havior were abbreviated for the clearance of the

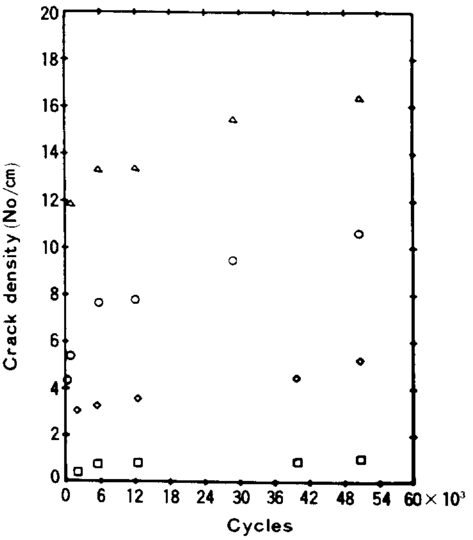

Fig. 6. Transverse crack development in fatigue loading.
△, central ply, 70% : ○, outer ply, 70% :
◇, central ply, 50% : □, outer ply, 50%

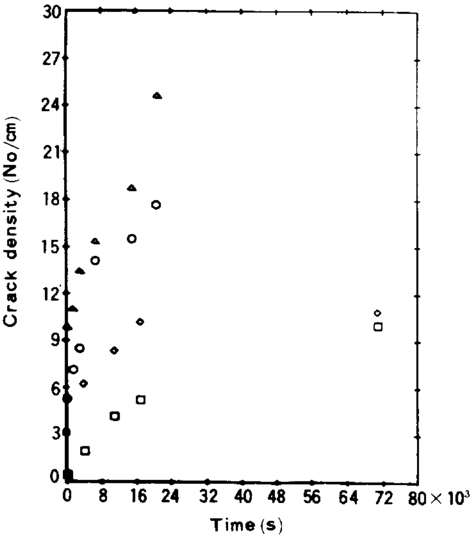

Fig. 7. Transverse crack development in fatigue—creep.
△, central ply, 70% : ○, outer ply, 70% :
◇, central ply, 50% : □, outer ply, 50%

gauge data. Because of the severe experimental conditions, those data were not very satisfactory. So the results of the transversal be-analysis.

CONCLUSIONS

The stiffness reduction procedure varies with the loading levels in fatigue and fatigue-creep. At very low stress level the stiffness reduction was very slow. At constrast this was very fast and nearly linear at high stress levels. The creep interruption in fatigue solicitation does not alter the number of fatigue cycles to failure in very high load level. It augments the density of transversal cracking in 90° plies. And it gives a little influence in the longitudinal behavior.

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