EFFECT OF STRESS RATIO ON FATIGUE CRACK GROWTH BEHAVIOUR IN C/C COMPOSITES

Junji Ohgi[1] and Koichi Goda[2]

[1]Department of Applied Mechanical Engineering Science, Yamaguchi University,
Tokiwadai 2-16-1, Ube, 755-8611 JAPAN
ohgi@yamaguchi-u.ac.jp
[2] Department of Mechanical Engineering, Yamaguchi University, JAPAN
Yamaguchi Univesity

ABSTRACT

In this study, Tension-tension fatigue tests were performed for compact tension specimen of C/C composites with $0^o/90^o$ layers. Then the effect of stress ratio on fatigue crack growth behaviours was investigated on the basis of fracture mechanics. The fatigue life was longer in R=0.5 than in R=0.1 at same P_{max} level. The fatigue resistance curve, which was proposed in this study, located 10% upper side in R=0.5 than in R=0.1. These results show that the cyclic load range affects the fatigue crack growth rate and the fatigue life compared with the mean load. The modified stress intensity factor ΔK_R was proposed, and then the crack growth rate da/dN was plotted against ΔK_R. As the results, a proper relation which da/dN increases with increase in K level was obtained.

1. INTRODUCTION

C/C composites have been developed for aerospace application due to their excellent properties such as low density, high heat resistance in inert gas atmosphere, high specific strength and so on. Additionally, since C/C composites have relatively higher fracture resistance than other CMCs, this material can be used as the structural components with high reliability. The fatigue properties are also important in long-time use of this kind of material as a structure. Although many researchers have been studying about the mechanical properties of this material, the properties related to fatigue have not been clarified sufficiently so far.

In this study, Tension-tension fatigue tests were performed for compact tension specimen of C/C composites with $[0/90]_6$. Then the effect of stress ratio on fatigue crack growth behaviours was investigated on the basis of fracture mechanics.

2. EXPERIMENTS

2.1 Material and specimens

2-dimensional C/C composite plate 'AC200' produced by ACROSS Corporation was used in this study. This material has $[0/90]_6$ structure, and thickness of one layer is about 0.4 mm. The density of this material is $1.7 g/cm^3$, and the flexural modulus of elasticity and tensile strength under 0^o directional loading are 44GPa and 98MPa, respectively. The compact tension (CT) type specimen with 60 x 57.6 x 5t (mm) was machined from the C/C plate as shown in figure 1. Then the notch with length of 34 mm and width of 0.8 mm was introduced in the middle of the specimen.

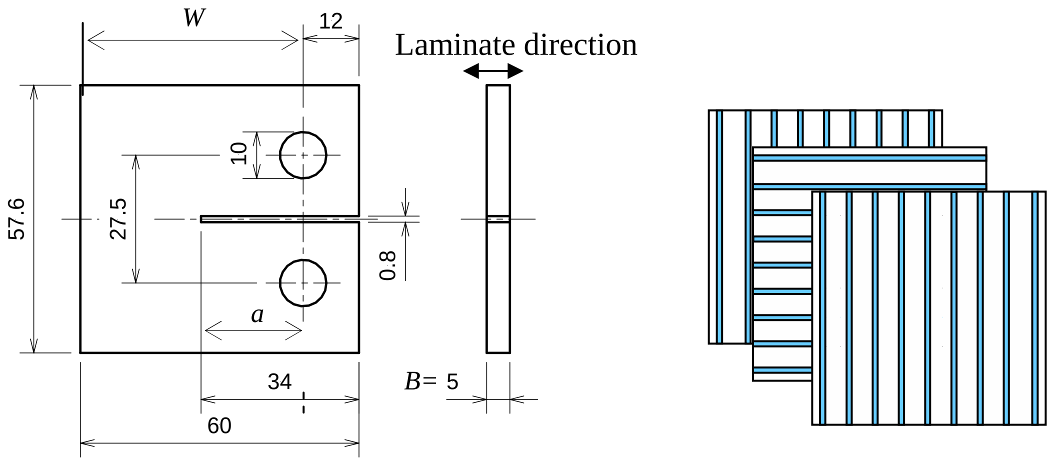

Figure 1: Shape and dimensions of CT specimen.

2.2 Fatigue test

The tension-tension fatigue tests were performed using closed loop type-electrohydraulic test system under the load controlled condition. The maximum load P_{max} was suitably decided and either of stress ratios (load ratios) R=0.1 or 0.5 was chosen. This means that if P_{max} is fixed the load range in the condition of R=0.1 is larger than that in R=0.5 while the mean load is smaller in the former than that in the later. The load wave frequency was 0.5 Hz.

2.3 Estimation of resistance curve in cyclic loading

The load incremental method was adapted to obtain the resistance curve under cyclic loading. The first the cyclic loading with relatively small P_{max} was applied to the specimen and then after the load-displacement response was saturated the P_{max} was slightly increased. This process was repeated until failure of the specimen occurred. The fracture resistance curve in cyclic loading was obtained by connecting upper tips in these saturated load-displacement hysteresis loops. Figure 2 and 3 show the loading pattern in this method and schema of the resistance curve in the fatigue loading.

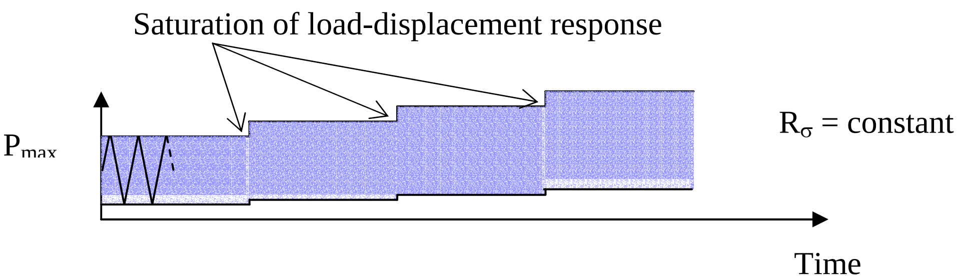

Figure 2: Loading pattern in load incremental method.

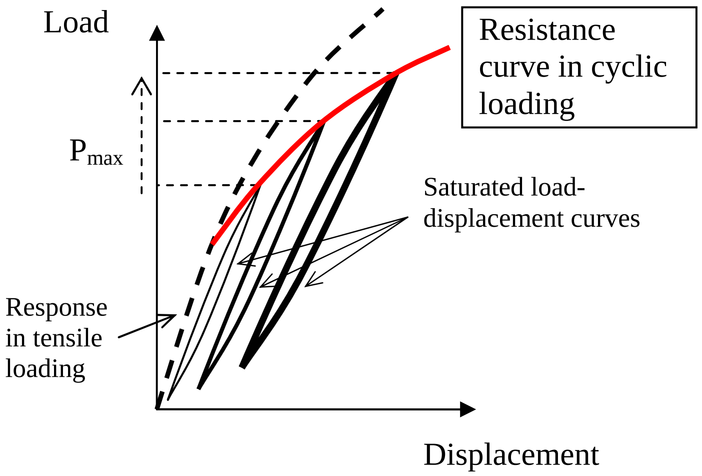

Figure 3: Schema of resistance curve in fatigue loading.

2.4 Compliance method

The compliance method was employed to estimate the crack length, which includes the original notch length, because of the difficulty in measuring the crack length visually. The compliance-crack length relation as a base data was obtained from tensile tests for the specimens with different notch length. Figure 4 shows the compliance-crack length curve of this specimen which was interpolated by the quadratic function.

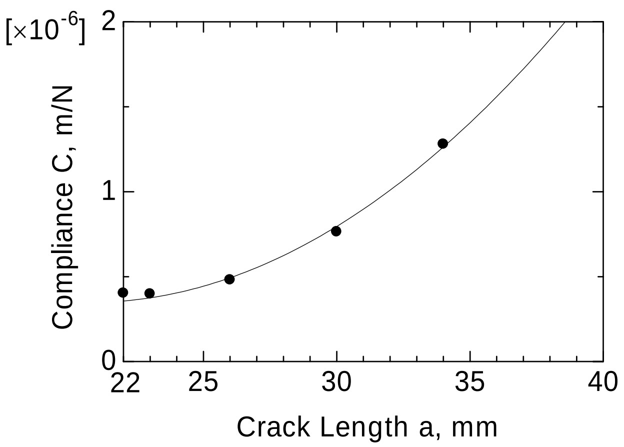

Figure 4: Compliance-crack length relation.

3. RESULTS AND DISCUSSION

3.1 Tensile test

The tensile test was performed for the CT specimen. The load-displacement response obtained from the test was shown in figure 5. The gradient of this relation gradually inclines upper 1200N where the crack initiates in the 90° layer and fiber breaking starts in 0° layer, additionally delaminations. The fracture toughness K_{IC} was calculated using following equation. The K_{IC} value was 13.8 MPam$^{1/2}$.

$$K = \frac{P}{BW^{1/2}} \times \frac{(2 + a/W)\left[0.886 + 4.64(a/W) - 13.32(a/W)^2 + 14.72(a/W)^3 - 5.6(a/W)^4\right]}{(1 - a/W)} \qquad (1)$$

Where *P* is maximum load in the load-displacement relation, and *B* and *W* are thickness and width of the specimen which are shown in Figure 1.

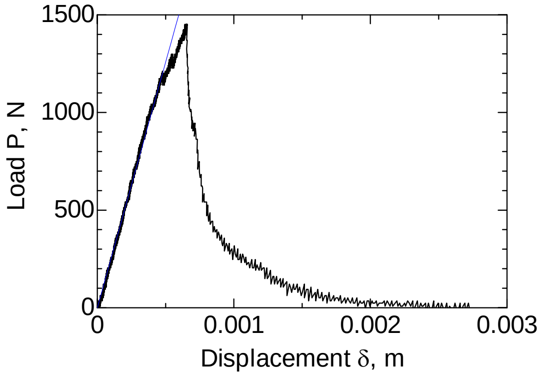

Figure 5: Load-displacement obtained from tensile test.

3.2 Fatigue life

The number of cyclic loadings for failure in each loading condition was shown in Table 1. The upper limit of maximum load P_{max} for 'not-failure' in stress ratio R=0.1 was 1150N which is about 80% of fracture load in tensile test (1450N). On the other hand, the upper limit of P_{max} in R=0.5 was 10% larger than that in R=0.1. This means that the fatigue life was much affected by the load range of cyclic loading rather than by the mean stress.

Table 1: The number of cyclic loadings for failure

		Stress Ratio R	
		0.1	0.5
Maximum Load P_{max}, N	1350	2 cycles	4
	1300	38	24
	1250	32	not failure
	1200	196	↑
	1150	not failure	

3.3 Crack growth behaviour

Figure 6 shows load-displacement response under cyclic loading of P_{max}=1200N and R=0.1. The compliance of load-displacement relation gradually increased with progress of fatigue process, because of development of damage around the notch tip.

The variation in crack length in fatigue process at R=0.1 is shown in figure 7, where the crack length was measured from the load-displacement response through the compliance method. According to this figure, the crack lengths increase rapidly in early fatigue process. Then the crack growth rate decreased gradually with progress of fatigue process, because the fiber bridging in 0^o layers on newly generated crack surface enhanced the crack growth resistance despite the crack length increased.

The crack growth rate da/dN was plotted against K_{max}, which was calculated substituting P_{max} for P in eq.(1). Figure 8 shows relation between da/dN and K_{max} at R=0.1. Although da/dN usually increases with increase in K level, in this case da/dN gradually decreased with increase in K_{max} under all loading conditions. This reason is that the crack growth resistance increase with progress of fatigue process as mentioned before.

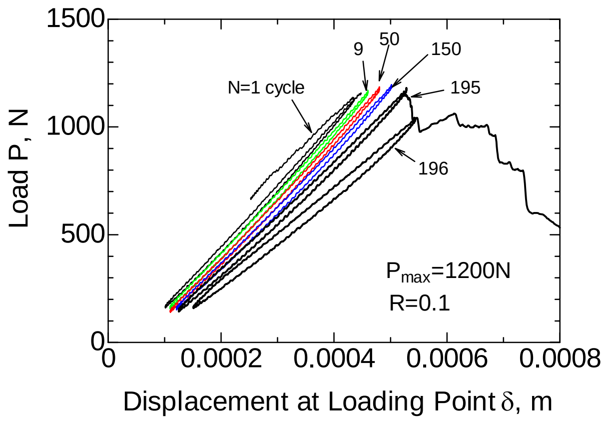

Figure 6: Load-displacement response under cyclic loading.

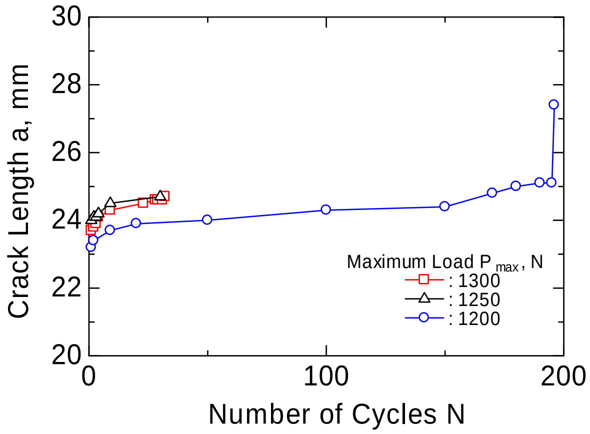

Figure 7: Variation in crack length.

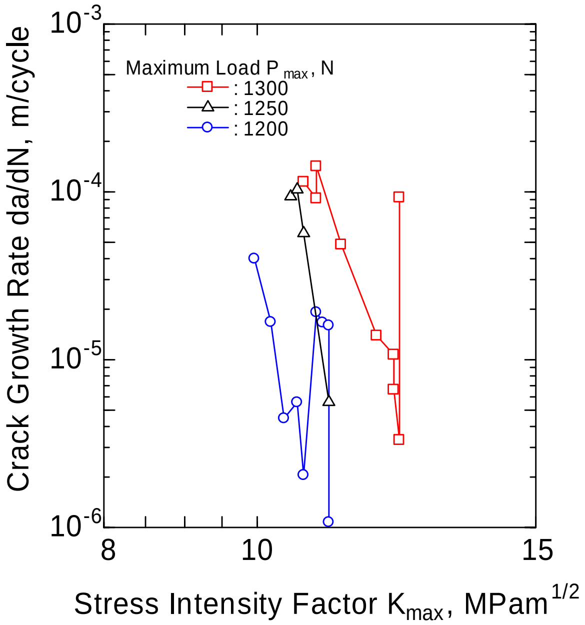

Figure 8: da/dN-K_{max} relation.

3.4 Resistance curve in cyclic loading

Figure 9 shows the resistance curves obtained from the load incremental method in the conditions of R=0.1 and R=0.5. According to this figure, the resistance curve in R=0.1 separated from the load-displacement curve in tensile test at around P = 800N. The resistance curve in R=0.5 was entirely located about 10% above the resistance curve in R=0.1. This result exhibits that the crack can extends much easier in R=0.1 than in R=0.5 at the same P_{max} levels.

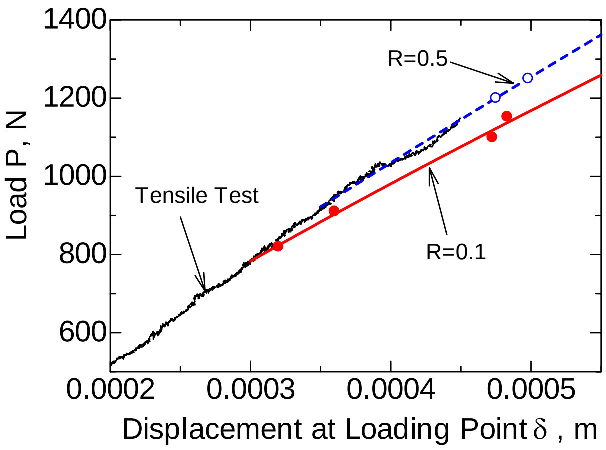

Figure 9: Resistance curve in cyclic loading.

The fracture mechanics parameter was modified on the basis of the resistance curve in cyclic loading. Figure 10 shows the schema of the calculation process. The first, the load increment ΔP_1, which is difference between P_{max} and the separation point P_1(=800N), was substituted for P in eq.(1) and the modified stress intensity factor ΔK_R was calculated. Then the cross point of the resistance curve and the straight line that connects upper tip with the point O, P_2 was estimated, and the next load increment ΔP_2 and ΔK_R was calculated. This process was repeated until fracture of the specimen occurred.

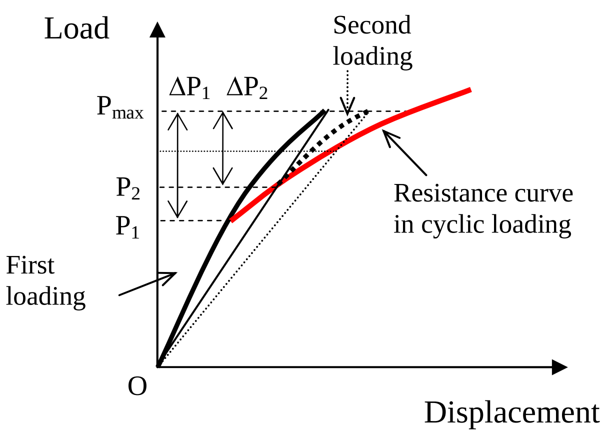

Figure 10: Schema of calculation process for modified fracture mechanics parameter.

The relation between da/dN and the modified stress intensity factor ΔK_R was shown in figure 11. According to this figure, a proper relation which da/dN increases with increase in ΔK_R was shown entirely. However this relation still shows the loading condition dependency. This point should be improved in future.

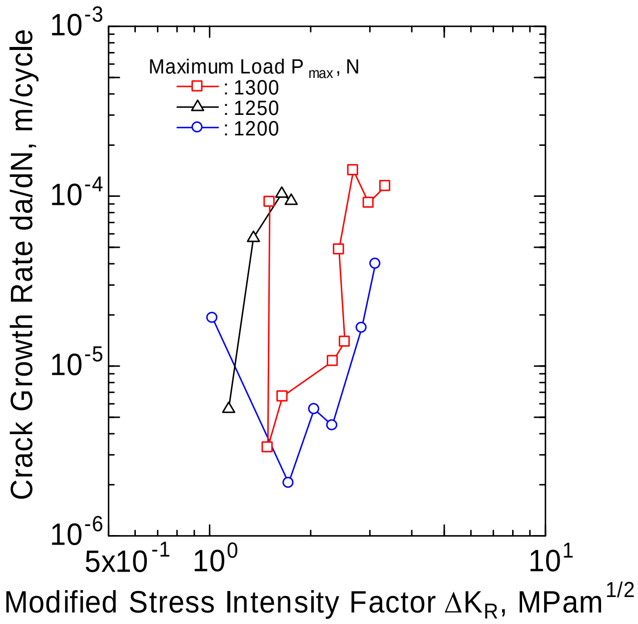

Figure 11: da/dN-ΔK_R relation.

4. CONCLUSIONS

The fatigue life was longer in R=0.5 than in R=0.1 at same P_{max} level. The fatigue resistance curve, which was proposed in this study, located 10% upper side in R=0.5 than in R=0.1. These results show that the cyclic load range affects the fatigue crack growth rate and the fatigue life compared with the mean load. The modified stress intensity factor ΔK_R was proposed, and then the crack growth rate da/dN was plotted against ΔK_R. As the results, a proper relation which da/dN increases with increase in K level was obtained.

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1- Ohgi, J., Jackson, J.H., Kobayashi, A.S. and White, K.W., "A FE Model of Carbon/Carbon Composite Fracture", *Proceedings of 8th International Symposium on Fracture Mechanics of Ceramics (FMC8)*, 2003.

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