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THERMAL-MECHANICAL FATIGUE BEHAVIOR OF A UNIDIRECTIONAL B/AL METAL-MATRIX COMPOSITE

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ABSTRACT: In this paper, the experimental study and macro-micro analysis about the behavior of thermal-mechanical fatigue (TMF) were conducted in B/Al metal-matrix composite with thermal cycle of 250℃ to 350℃. The result showed that S-N curves of in-phase and out- phase intersect at the point of FPF, above which the life of in-phase TMF was less than that of out-of-phase TMF but the case was opposite below the point. Otherwise the life of TMF was always less than that of 250℃ isothermal and 350℃ isothermal. Furthermore the fatigue crack came of the interface between fiber and matrix material because the interface reaction acted as the primary part of damage on TMF.

KEYWORDS: Thermal-mechanical Fatigue (TMF), Metal Matrix Composite (MMC), In-phase, Out-of-phase

BACKGROUND

In many aerospace and aeronautical applications, metal-matrix composites (MMC) will be subjected to fatigue loading along with a superimposed variation in temperature. When variation in load and temperature occur simultaneously, it is referred to as thermal-mechanical fatigue (TMF). This type of loading condition is expected to be one of severe type. Because a large difference in the coefficient of thermal expansion between the matrix and fiber conduced them to expand at a different rate and then the reinforcing fiber with temperature excursions caused internal stresses to develop. Thus there is a need to understand the thermal-mechanical fatigue behavior of metal-matrix composites[1,2].

MATERIAL AND TEST PROGRAM

The material used in this study was B/Al metal matrix composite. The thermal-mechanical fatigue tests were conducted using the straight rectangular specimens of 160mm length by 10.0 mm width which were cut using a diamond cutoff wheel. The 0° fiber were in the length-wise direction.

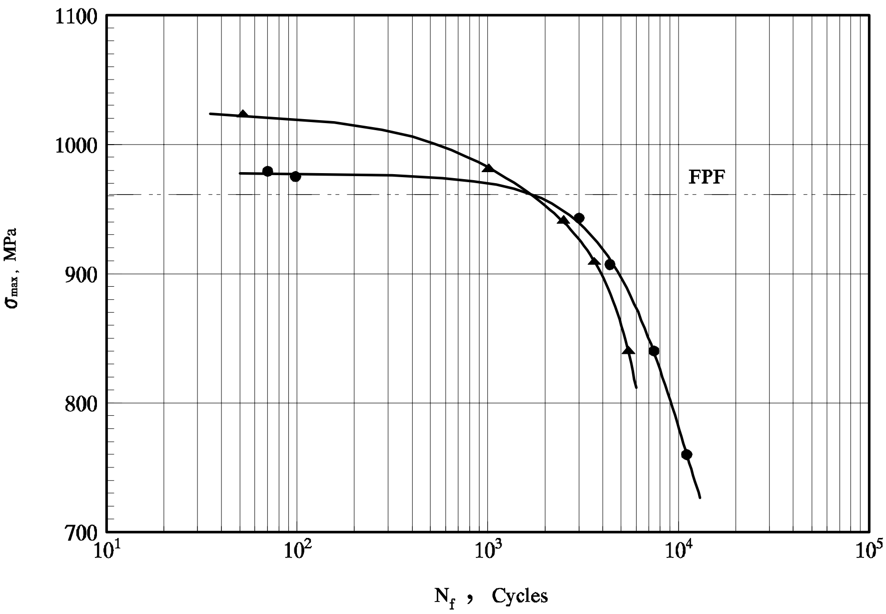
The thermal-mechanical fatigue tests were conducted on the servohydraulic machine MTS-810. The temperature control system allowed the specimens to thermal cycle between 250℃ and 350℃ in a period of 60s.

The mechanical fatigue under load control mode at a load ratio of 0.1 with a triangular waves. The in-phase thermal-mechanical fatigue tests involved mechanical fatigue in-phase with thermal fatigue, i.e. maximum temperature occurred at the time of maximum load. The out-of-phase thermal-mechanical fatigue tests involved mechanical fatigue which was 180℃ out-of-phase with respect to thermal fatigue, i.e. maximum temperature occurred at the time of minimum load. The time period of both thermal and mechanical fatigue cycles was 60s.

A total of 11 specimens were tested to characterize thermal-mechanical behavior: sixin-phase tests at maximum stress levels of 760, 840, 907, 943, 975, 979MPa respectively, and the other five out-of-phase tests at 840, 909, 941, 981, 1023MPa, respectively. The another four specimens were conducted on isothermal tests.

TEST RESULTS AND ANALYSIS

Results of all thermal-mechanical fatigue tests are showed in Fig.1. Fig.1 compares the fatigue lives (S-N curves) of in-phase and out-of-phase TMF tests on the basis of maximum applied stress. There is a cross-over point between S-N curves from in-phase and out-of-phase thermal-mechanical fatigue tests. It can be seen from this figure that fatigue life of in-phase TMF conditions at stresses above FPF stress level is considerably less than which was obtained under comparable out-of-phase TMF conditions. On the other hand, for stressed below the FPF stress level under in-phase loading conditions, fatigue life was increased considerably from those obtains under the comparable out-of-phase conditions. Thus it can be easily concluded from Fig.1 that the fatigue life of the tested B/Al laminated composites depends not only on the test condition but also on the applied load (or stress) level. This behavior in MMC is due to the considerable mismatch in the coefficient of thermal expansion between matrix and fiber. In detail, it can be explained from the point of view of micromechanics. Fiber can support higher stress level than matrix under the conditions of in-phase (showed in Fig.2), but the case was opposite under the conditions of out-of-phase (showed in Fig.3)(Some other researchers such as Dale L. Ball had mentioned)[3]. Thus there was different control mechanism between above and below FPF on TMF life.



●— in-phase ▲— out-of-phase temperature:250~350℃

Fig.1 the S-N curves of B/Al under thermal-mechanical fatigue

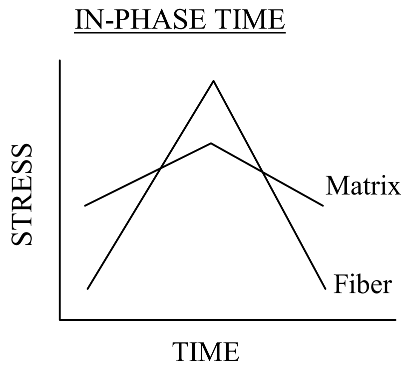


Fig.3 Variety of stress on fiber and matrix on in-phase TMF

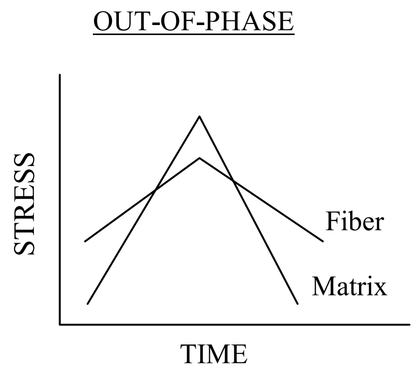
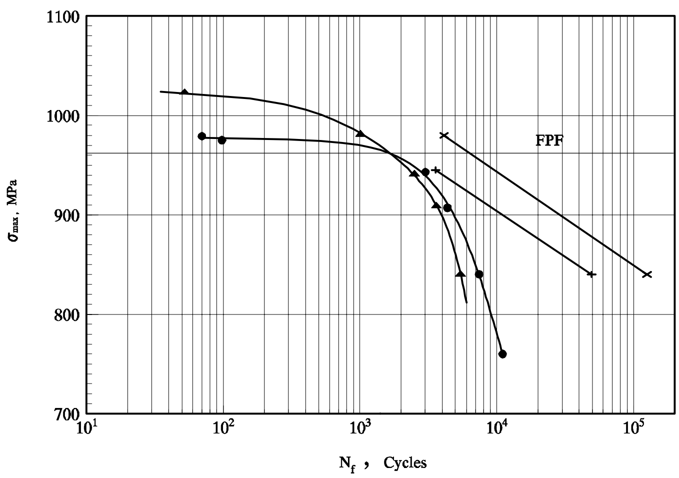


Fig.3 Variety of stress on fiber and matrix on out-of-phase TMF

The reaction between fiber and matrix on high temperature is very important to forming and expanding of fatigue damage on TMF. For high stress level (above the FPF), the surface of specimens on TMF tests was uneven because cracks expanded at different height and ruptured on the breakpoint. Before the fiber was fractured, ductile fracture occurred on matrix material because of local stress concentrating on fractured fiber and constriction on the point of restrict yield for matrix material.[4] Otherwise for low stress level (below the FPF), following the increase of cycles, many cracks which formed on the interface between fiber and matrix and expanded perpendicularly to the fiber expanded slowly. Because interface endured long time of thermal-cycles, it separated from the fiber and matrix, which caused transverse cracks to be departure from different direction. And after matrix material ruptured, fracture occurred because of the rupture of fiber as the stress increased.

For the sake of comparing the lives between TMF and isothermal tests, two isothermal tests on 250℃ and 350℃ which were the same frequency to TMF tests were conducted. The result is showed in Fig.4. It can be seen from Fig.4 that the lives of TMF are less than that of isothermal tests for B/Al composite. So the damage of TMF is very bad for metal matrix composite and it is very important to study the behavior on TMF for MMC.



× — isothermal of 250℃, + — isothermal of 350℃

•— in-phase ▲— out-of-phase temperature:250~350℃

Fig.4 comparison of the S-N curves between TMF and isothermal

CONCLUSION

The experimental results for TMF and isothermal tests for B/Al composite are presented in this paper. There is a cross-over point between S-N curves from in-phase and out-of-phase thermal-mechanical fatigue tests. The lives of TMF are less than that of isothermal tests for B/Al composite. Fatigue cracks start at the interface between fiber and matrix and the reaction between fiber and matrix on high temperature was very important to forming and expanding of fatigue damage on TMF for B/Al composite.

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