Fretting Fatigue Behavior with Double Contact Pads in A2024-T4 Aluminum Alloy

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1. Introduction

Fretting fatigue is a serious problem in various machines and structures, where two components are in contact and subjected to cyclic loading [1]. Many research works on fretting fatigue have been reported. However, in most of the research works, fretting fatigue tests were carried out using single pair of contact pad. In actual applications, such as gas turbine and aero engine turbine, multiple number of blade/disc slot-dovetails joints are connected with the rotor assembly, therefore the number of contact region supposed to fretting fatigue is not single, but multiple [2, 3]. Since the stress state at contact region is not the same for single and multiple contact conditions, it is necessary to study and understand the fretting fatigue behaviour under multiple contacts condition. In the present study, the effect of double contact pads, which is simulating the multiple contact conditions, on fretting fatigue behaviour of A2024-T4 aluminum alloy has been investigated. Finite Element Analysis (FEA) was also performed to evaluate the stress distribution at the contact edge.

2. Experimental Procedure

The material used for specimen and contact pad was A2024-T4 aluminum alloy. The chemical composition and mechanical properties of A2024-T4 aluminum alloy used are shown in Tables 1 and 2, respectively. Shape and dimensions of the specimen with two parallel flats in the gauge part is shown in Fig. 1(a). The geometry of a bridge type contact pad is shown in Fig. 1(b). Prior to testing, testing parts of the specimen and contacting surfaces of the contact pads were polished parallel to the loading direction by using emery papers with grit number of #1000 in finally.

Table 1 Chemical composition of A2024-T4 (wt %).

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
0.5	0.5	3.8	0.3	1.2	0.1	0.25	0.15	Rem

Table 2 Mechanical properties of A2024-T4.

Young's Modulus, GPa	Tensile Strength, MPa	0.2% Proof Stress, MPa	Elongation, %
73	450	320	19

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Fretting fatigue tests were conducted with a servo-hydraulic test machine at stress ratio of 0.1, frequency of 15Hz and the applied constant contact pressure of 100 MPa in laboratory air. A schematic of fretting fatigue experiment setup using double contact pads is shown in Fig. 1(c).

FEA was carried out using commercial software MARC to estimate the stress distribution near the contact regions. The minimum mesh size used in a model at the contact region was $5\mu\text{m}$. The coefficient of friction used was 0.5 and the procedure in detail for evaluation of tangential stress range is given in Ref. [4].

3. Results and discussions

3.1 Effect of using single and double contact pads on fretting fatigue strength

S-N curves for fretting fatigue test of A2024-T4 using single contact pad and double contact pads are shown in Fig. 2. It can be seen from the figure that the fretting fatigue strength of the specimen with double contact pads was lower than that of the specimen with single contact pad. It can also be observed that the reduction of strength in fretting fatigue with double contact pads compared to single contact pad is significant when the gap between double contact pads is small. It has been reported that fretting fatigue strength decreases significantly with decreasing pad-to-pad clearance [3]. On the contrast, the reduction in fretting fatigue strength is not significant, if the gap between double contact pads is large. In the present study, the fretting fatigue strength of the specimen with double contact pads of 4mm gap between the contact pad pairs is almost the same or little less, compare to that of the specimen with a single contact pad.

Fig. 1 Geometry and set up of specimen and contact pad.

Fig. 2 SN-curves for fretting fatigue test using single and double pads.

3.2 Fracture surface observation

Fracture surface of fretting fatigue tested specimen is shown in Fig. 3. From the figure, it can be observed that in the case of specimen tested with double contact pads with 1mm gap, multiple crack nucleation sites are found at the contact edge. In case of specimen tested with single contact pad, only one crack nucleation site is found at the contact edge. In addition, it was observed that for specimens tested using double contact pads with 1mm gap, the failure due to fretting fatigue always occurred at the external edge of two contact pads, i.e., in location B shown in Fig 1(c). In the case of specimen tested using double contact pads with 4mm gap, the failure due to fretting fatigue occurred either at location A or B shown in Fig 1(c). In order to understand the behaviour more clearly, tangential stress at the contact region was evaluated with FEM.

3.3 Effect of single and double contact pads on tangential stress range

The relationship between the maximum tangential stress range at the contact edge and stress amplitude applied to the specimen for the single contact pad case and the double contact pads cases with 4mm and 1mm gaps are shown in Fig. 4. As seen from the figure, the maximum tangential stress range was high in the case of the double contact pads with 1mm gap. In the case of the double contact pad with 4mm gap, the maximum tangential stress range was nearly the same as that obtained with the single contact pad case. It has been reported that a fretting fatigue crack nucleates from the point of the maximum tangential stress [5, 6]. Therefore, in fretting fatigue, tangential stress plays a dominant role for early crack nucleation and accelerating of crack growing. And also, it can be observed by previous researchers, if the maximum tangential stress range is large, surface damage due to fretting would be significant and hence the fretting fatigue strength reduction rate would be high [4, 7]. In the present study, the lower fretting fatigue strength was obtained in the case of the double contact pads with 1mm gap due to the higher tangential stress range as shown in Fig. 4.

Fig. 3 Fracture surface of fretting fatigue tested specimens at stress amplitude 90MPa (arrows indicate crack nucleation sites).

Fig. 4 Relations between stress amplitude and maximum tangential stress range for single contact pad and double contact pads.

According to the failure location explained in the previous section, it can be speculated that if the gap between double contact pads is small, the rigidity of specimen in region between double contact pads would be high. The relative slip amplitude and tangential stress range at the external edge of two contact pads (i.e., location B in Fig. 1(c)) are higher than those at the contact regions between the double contact pads (i.e., point A in Fig. 1(c)). Therefore, failure occurred at location B. If the pad gap is large, the each pair of the double contact pads may act like two single contact pads and hence the fretting fatigue strength is almost the same as that obtained with single contact pad.

4. Conclusions

In the present study, the effect of double contact pad on fretting fatigue behaviour of A2024-T4 aluminium alloy has been investigated. The gap between double contact pads showed significant influence on fretting fatigue strength. Lower fretting fatigue strength and failure at the external edge of the double contact pads were observed when the gap between the double contact pads was small. On the other hand, if the gap of the double contact pads was wider, it behaved like two single contact pads and failure occurred at contact edges but not at the specific position. Those results would be due to difference in tangential stress range at the contact regions. Higher tangential stress range was observed in the case of double contact pads compared with the case of single contact pad.

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