EFFECT OF STRESS ON MULTIPLE SITE DAMAGE

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Abstract

Two kinds of panels with three rows of hole made of LY12-CZ aluminum alloy were tested under cyclic loads to study multiple site damage (MSD). It was found that panels were broken in three typical failure types; the probabilities of the first broken holes and failure happened at the middle row was almost the same as those happened at two lateral rows. The results also revealed that the stress level had a significant effect on the appearance of MSD: the larger maximum stress meant the easier occurrence of MSD; when the maximum stress was low to a certain extent, MSD would hardly happen.

1 Introduction

The Aloha Airlines incident warned engineers and technicians that it was easy to find multiple cracks in details of aircraft. These cracks then developed into multiple site damage or widespread fatigue damage (WFD) when the stress levels of various details of aircraft structures had little difference. Compared with local damage, multiple site damage can lead to a series of more serious consequences[1]: crack propagation for MSD is increased; the residual strength is reduced in a much shorter time due to the link up of small cracks; furthermore, the critical crack length is decreased obviously.

The research on MSD can be organized in the following aspects: studying the mechanism of crack initiation[2-5] and propagation[6-9] of MSD through tests and finite element methods; establishing propagation and resident strength models using mathematical tools [10-11].

In this study, thirty-eight crack-free panels with holes made of LY12-CZ aluminum alloy were aligned perpendicular to tensile loads. Sizes, morphologies and distributions of cracks were recorded to analyze the effect of stress on multiple site damage.

2 Specimens, testing equipment and material mechanical properties

Two kinds of specimens were applied in tests: panels with three parallel rows of holes (a-type) and panels with three alternate rows of hole (b-type). The material of specimens was LY12-CZ and their thickness was 3mm. The front and back sides of panels were defined as Side Ⅰ and Side Ⅱ. Detailed geometrical sizes of specimens were shown in Fig. 1 and Fig. 2.

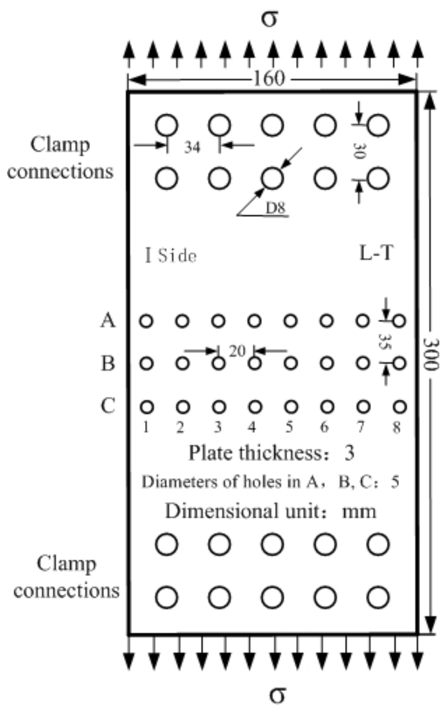

Fig. 1. Panel with Three Parallel Rows of Hole

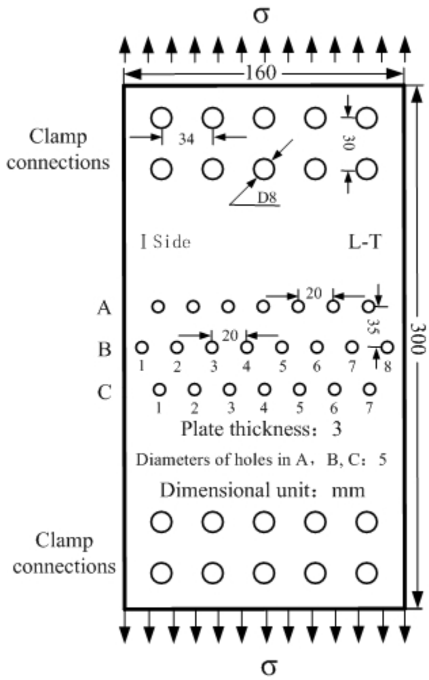

Fig. 2. Panel with Three Alternate Rows of Hole

Tensile tests were carried out on eight standard specimens whose material and thickness were the same as above thirty-eight specimens. The mechanical properties were given in Table 1.

Table 1. Mechanical Properties of LY12-CZ

Elastic modulus E, GPa	Yielding strength σ_s, MPa	Ultimate strength σ_b, MPa	Elongation δ, %
70.92	341.36	471.49	18.94

3 Fatigue tests

3.1 Loading conditions

Instron8801 electro-hydraulic servo machine was used in tests, as shown in Fig. 3. Crack dimensions were measured with both vernier callipers and JVC reading microscope.

The maximum loads ranged from $0.2\sigma_b$ to $0.4\sigma_b$, as shown in Table 2 and Table 3; loading stresses were minimum net section stresses of specimens; stress ratio R=0.06; initial frequency was 10Hz and the frequency was reduced gradually when cracks appeared in order to observe the growth and linkup of cracks. Fixtures were located at the end of specimens, and the material of fixtures was 45 steel. Bolts were used to joint clamps and specimens together and loads were also transferred to specimens by them. Dimensions of clamp connections were given in Fig. 1 and Fig. 2.

Fig. 3. Specimen Gripped in Fatigue Machine

3.2 Test results

Test results were listed in Table 2 and Table 3. Capital letters in both tables represented rows containing the first broken holes. Because the structural details were almost the same, more than one cracks would be observed, which led to several capital letters appeared in Table 2 and Table 3 when recording the first broken holes. Symbols R and L represented the right and the left of holes respectively. For example, R_{A6} denoted the first crack that found in the right of the 6th hole at row A.

The distribution of first broken holes and fracture location were listed in Table 4.

3.3 Analysis of test results

(1) Tirty-eight panels were broken in three failure types: MSD, non-MSD, fracture at clamp connections. Non-MSD referred to single crack failure for specimens #1～#5 and #15; although #6 occurred single crack at both row A and row C which ruptured at row A finally, such

Table 2. Test Results of a-type Specimens

σ_{max}	Specimen number	First broken holes	Fracture location	Fracture mode
$0.2\sigma_b$	#1	R_{A6}	A	non-MSD
$0.25\sigma_b$	#2	R_{B5}	B	non-MSD
	#3	L_{B4}	B	non-MSD
	#4	R_{B7}	B	non-MSD
	#5	L_{A4}	A	non-MSD
	#6	L_{A5}	A	non-MSD
$0.3\sigma_b$	#7	L_{A3}	A	MSD
	#8	L_{C3}	C	MSD
	#9	R_{C8}	C	MSD
	#10	L_{B6}	A	MSD
	#11	A、B	A	MSD
$0.35\sigma_b$	#12	B、C	B	MSD
	#13	A、C	C	MSD
	#14	A、B、C	B	MSD
	#15	L_{C8}&R_{C8}	C	non-MSD
	#16	A、B、C	A	MSD
	#17	Failed at clamp connections		
	#18	Failed at clamp connections		
$0.4\sigma_b$	#19	L_{C4}&R_{C4}	C	MSD
	#20	R_{B4}	B	MSD
	#21	L_{B6}&R_{B6}	B	MSD
	#22	L_{A6}	B	MSD

Table 3. Test Results of b-type Specimens

σ_{max}	Specimen number	First broken holes	Fracture location	Fracture mode
$0.3\sigma_b$	#23	A、B、C	A	MSD
	#24	R_{B4}	C	MSD
	#25	R_{B2}	B	MSD
	#26	A	A	MSD
	#27	L_{B1}	B	MSD
	#28	B	B	MSD
$0.35\sigma_b$	#29	R_{B8}	B	MSD
	#30	L_{C4}	C	MSD
	#31	R_{C5}	B	MSD
	#32	Failed at clamp connections		
	#33	R_{C6}	C	MSD

σ_{max}	Specimen number	First broken holes	Fracture location	Fracture mode
$0.4\sigma_b$	#34	Failed at clamp connections		
	#35	B、C	B	MSD
	#36	B	B	MSD
	#37	C	C	MSD
	#38	A、B	B	MSD

(Continuation of Table 3)

Table 4. Distribution of Rows with First Broken Holes and Fracture Location

	No. of rows with first broken holes		No. of rows with fracture location	
	A or C	B	A or C	B
a-type	14	10	12	8
b-type	8	9	6	8
Sum	22	19	18	16

phenomenon was not a typical MSD failure, so #6 also could be considered as single crack failure. As shown in Fig. 1, because the net section stresses undertook by row A, B and C were basically identical with that undertook by clamp connections, four specimens failed at clamp connections.

(2) It can be seen from Table 4 that the probability of the first broken holes happened at the middle row (Row B, totally 22 specimens) is almost the same as that happened at rows A and C (totally 19 specimens); on the other hand, the specimens failed at the middle row were 18 while the specimens failed at the lateral rows were 16. Therefore, it is suggested that the occurrence probabilities of the first broken holes and fatigue failure were nearly equal between the middle row and the lateral rows.

(3)For a-type and b-type specimens, when the maximum stresses were $0.3\sigma_b$, $0.35\sigma_b$ and $0.4\sigma_b$, 27 panels had developed into multiple site damage except for #15 and four specimens failed at clamp connections. However, at maximum stresses of $0.2\sigma_b$ and $0.25\sigma_b$, six panels occurred only single crack. This phenomena indicated that the stress level had an important influence on the emergence of MSD: the larger maximum stress meant the easier occurrence of MSD; when the maximum stress was low to a certain extent, MSD would hardly happen.

The main reasons of such phenomenona are: some original defects which are relatively small in specimens are gradually becoming bigger provided that the local stress intensity factor is larger than K_{op}, therefore, the higher the maximum stress applied, the smaller the defects which probably become detectable cracks. When the maximum load is high enough, some initially very small defects may become detectable cracks and MSD will occur. On the other hand, if the maximum stress is too low, only few defects can reach the K_{op} and most probably, only one becomes detectable crack and the crack has a higher and higher crack propagation rate because of larger stress intensity factor at its tip compared with other parts. While the local stress is redistributed, the specimen is destructed by single crack eventually.

On the other hand, in engineering, as time goes on, serious degradation of material properties can be induced by material aging, surface corrosion and so on. Therefore, environmental affect and service period should be taken into account in further researches.

4 Conclusions

Based on the fatigue test results of two kinds of aluminum alloy panels, multiple site damage that often occured in aging aircrafts was studied. The conclusions can be concluded as follows:

(1) The probabilities of the first broken holes and fatigue fracture occurred at the middle row were almost identical to those occurred at the lateral rows.

(2) The larger maximum stress was advantageous to the occurrence of MSD; when the maximum stress was low to a certain extent, MSD would hardly happen.

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