FATIGUE PROPERTIES OF DOUBLE LAP-TYPE SINGLE-BOLT COMPOSITES

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Keywords: Composite joints, Fatigue testing, Fatigue life, Non-destructive testing, Scanning Electron Microscope

ABSTRACT

The effect of interference amount on the fatigue life of bolted composite joints was investigated through experimental approach. Mechanical fatigue tests were performed on double lap-type joint made of carbon-bismaleimide composite with single bolt. The interference fits ranges from zero to one percent, including four cases, 0%, 0.5%, 0.75% and 1%. After the fatigue test, scanning electron microscope (SEM) was used to observe the damage around the open holes of joint laminates. Test results show that the interference fitted specimens do have improved fatigue life, compared with the neat fit specimens. The best interference fit is 0.75% in this study.

1 INTRODUCTION

Owing to their high strength-to-weight and stiffness-to-weight ratios, polymer composite materials have been widely used in aerospace and other engineering industries [1-2]. It is required for the composites to be jointed either to composites or to metals. Mechanical fasteners are usually used to form joints. Bolted joints are the dominant fastening technology used in jointing primary structural parts[3-4].

Interference fit can be generally used to reduce the stress concentration factors and the magnitude of the local stress. In case of fatigue loading, the fatigue life of composite joints can be greatly improved by interference. However, there are few studies on the interference fit actions for the pin/hole and/or bolt/hole interference fit joints[5-8]. Hüyüka et al.[9] examined the elastic-plastic interference fitted joints for pin-tube geometries through physical trials and numerical models. Their results showed that there were three distinct stages as the pin was pushed into the tube and an optimum geometry maximizing the joint strength exists. Chakherlou et al.[10] investigated the effect of interference fit on fatigue life of holed plate of mechanical joints made of Al 7075-T6 alloy. The fatigue tests were conducted on an open hole specimen and the specimens with 1%, 1.5%, 2% and 4% nominal interference fit sizes at different cyclic longitudinal loads. Their results showed that interference fit increased fatigue life compared to the open hole specimen.

In the present work, an experimental study is carried out to investigate the fatigue behavior of bolted joints in composite laminates with different interference fit sizes. The surrender and the surface of the hole are estimated by Non-Destructive Evaluation and Scanning Electron Microscopy. The effects of interference fit on mechanical properties are examined in detail.

2 SPECIMENS AND EXPERIMENTAL INVESTIGATION

2.1 Material and Specimen

A carbon fibre reinforced bismaleimide composite, referred to as T700/QY9611, is selected in the experimental studies. All of the specimens are cut from the composite laminates according to the mechanical tests. Each ply of the specimen has the same material properties which are listed in Table 1. The specimens are supplied by Chengdu Aircraft Design and Research Institute of China. The dimensions of the specimen are taken to be L=160 mm, a=44 mm, b=50 mm, c=4 mm, e=40 mm and δ=4 mm. The specimen has a fastener hole with diameter ϕ =8 mm. All specimens have the same values (w/d = 5.5 and e/d = 5), and the total length of the specimen is equal to 260 mm.

Table 1: Properties of the composite materials

Material properties	Symbol		Data
Density	ρ	[g/cm^3]	1.57
Elastic modulus	E_{1t}	[GPa]	128
Compression modulus	E_{1c}	[GPa]	123
Tensile strength	X_t	[MPa]	2910
Compression strength	X_c	[MPa]	1250
Poisson's ratio	υ_{12}	–	0.29

For the clamping-up of experimental machine, a filler plate made of aluminum alloy is used. Four sizes of interference fits, 0%, 0.5%, 0.75% and 1%, are considered in the tests. The interference fit size can be expressed by

$$I=\frac{D-d}{D} \tag{1}$$

where D is the bolt diameter.

The failure definition under fatigue loading is rather complex for a bolted joint. The best way of applying fatigue stress level is obtained from the static bearing strength. It is necessary to adopt a relatively simple way to monitor bearing damage during a fatigue test. The extensometer measuring system is used to determine the hole elongation. Generally, testing is not terminated until enough bolt-hole elongation (hole wear) is produced (it may be 4% deformation of hole diameter) or 3,000,000 cycles are achieved.

For the fatigue tests, the cycle loading applied to all specimens has a constant amplitude sine wave with a stress ratio of R=-0.1. Fatigue tests are conducted according to the ASTM D 6873 standard[27] at a room temperature of 23±3 ^{o}C. For each specimen group, the maximum of fatigue load is about 90% of ultimate failure load of static test, while the minimum of fatigue load is about -10% of ultimate failure load of static test. The temperature rise caused by relative motion between the joint parts is a major factor to be considered in the test. If the temperature rise becomes excessive, it may cause premature failure of the joint. Frequency 5 Hz is selected to avoid this. In addition, a cooling fan with compressed air directed onto the bolt is implemented, and the temperature of the bolt is monitored by infrared thermometer. It should be noted that the temperature on the surface of the bolt is likely to be less than the temperature in the interior of the joint, the target maximum temperature for the bolt surface is set to be 60 ^{o}C, and test frequency is adjusted to try to maintain temperatures below this value.

An extensometer is used in order to measure the bolt-hole elongation for the single-bolt double-lap bolted joint specimens. Each test is repeated at least five times and the mean values are taken as test results under 95% confidence level.

The microscopy observation can give the information on voids, delaminations, fibre distributions and other damage situations. The following evaluation methods are chosen to compare the composite joints considered. Prior to and in specific intervals during fatigue testing, all specimens are inspected by using an acousto-ultrasonic device (Phasor XS by GE). This portable device is versatile and allows the detection of flaws which may be either debonding or delamination within the patch. However, the instrument does not provide information about the type of the defects. Consequently, only the extent and position of the defects are measured during inspection. This non-destructive evaluation (NDE) instrument has A-Scan, B-Scan, C-Scan and S-Scan functions. The type of probe used in this testing is phased array with 5 MHz frequency and 32 wafers, which can detect the delamination, crack and so on.

In order to evaluate the extrusion damage of hole after fatigue testing, scanning electron microscopy (SEM) is employed to observe the surface morphology and fracture behaviors of composites. The SEM samples are coated with approximately 10~20nm of gold before examination with a ZEISS-ULTAR PLUS apparatus. As the type of the failure mode (crushing/delamination) could not be known after testing, the specimens' damage type can be evaluated by this instrument.

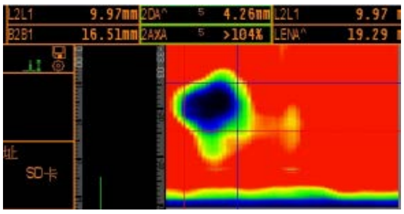
3. RESULTS

All tests were made with double lap joints under R-ratio = -0.1 fatigue loading. Tests was load-controlled in sinusoidal wave at frequency 5 Hz adjusted to limit specimen surface temperature below 60 ^{o}C. Fatigue lives of bolted joints with four interference fit sizes, 0% (neat fit), 0.5%, 0.75% and 1%, were obtained. There are 6 specimens for each interference-fit. The average value of each case meets the 95% confidence level. Typical results for these four cases are listed in Table 2. Selecting the appropriate size of interference fit can greatly improve the fatigue properties of composite bolted joints. From Table 2, it can be clearly seen that T700-3 group with 0.75% interference fit has the highest fatigue life among the four cases. The fatigue life will be reduced whenever the size of interference fit is higher or lower than 0.75%.

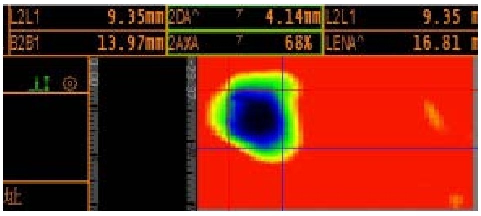
In order to observe what type damage occurrs during fatigue load cycling, the specimens' damage situation is evaluated by NDE after fatigue life testing. Typical results of NDE measurement are shown in Figure1. It can be seen that the bolt-hole elongation has a different size under these four cases. It might also be noted that the sizes of the bolt-hole elongation provided by NDE instrument are just relative value which can be compared with each other. The percentage of hole damage is defined by

$$P_{\mathrm{h}} = \frac{D' - D}{D} \quad P_h = \frac{D' - D}{D} \tag{2}$$

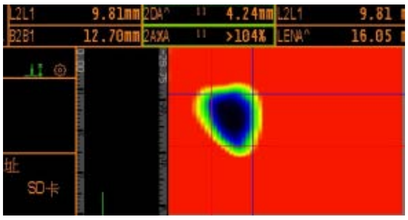
where D' is the bolt-hole diameter after fatigue testing measured by NDE.



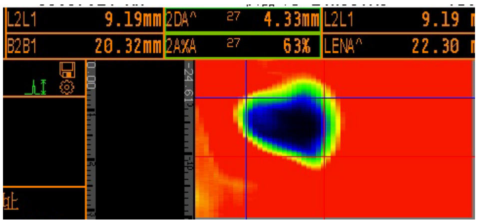
(a) Interference fit of 0%



(b) Interference fit of 0.5%



(c) Interference fit of 0.75%



(d) Interference fit of 1%

Figure 1 NDE pictures on the surrender of the hole

The percentage of hole damage with different interference fits is measured and plotted in Figure 2. The results show that the percentage of hole damage is reduced from 90% to 50% when the size of interference fit is increased from 0% to 0.75%. The percentage of hole damage reaches 140% when the size of interference fit is 1%.

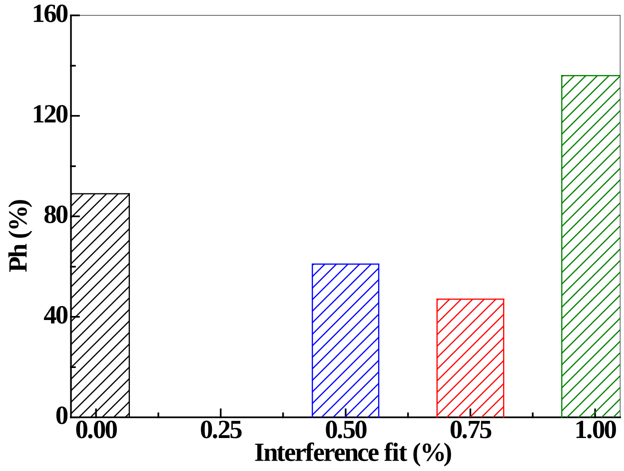
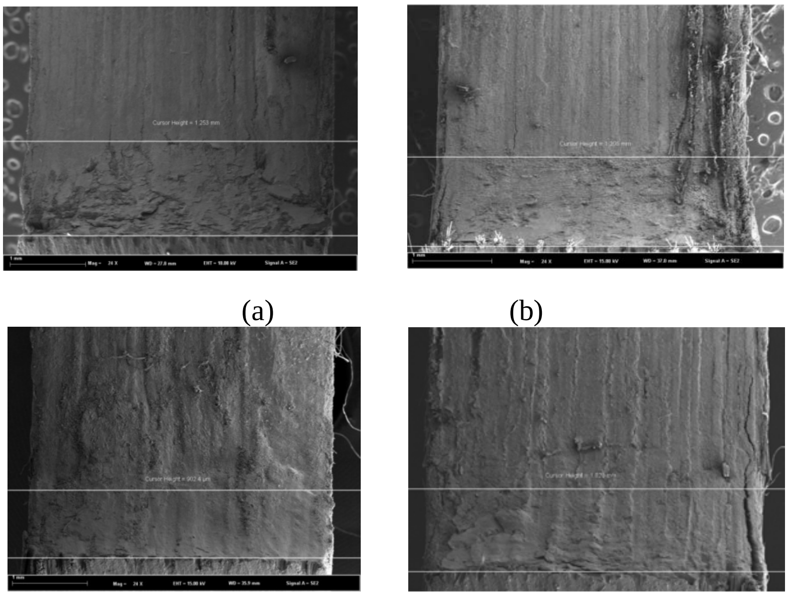


Figure 2 Percentage of hole damage with different interference fits

SEM micrograph images were taken on the surface extrusion sections of the hole with 0%, 0.5%, 0.75% and 1% interference fits, respectively. Figure 3 showed SEM micrographs of the fractured hole surfaces around the extrusion zones after the fatigue tests. The abrasion area is the biggest with 0% interference fit and it becomes small with the interference fit. It is found that the abrasion area is reduced when the size of interference fit is increased and the area with 0.75% interference fit is the smallest. The interference fit actions have been investigated in the present experimental studies.

Table 2: Fatigue lives with four sizes of interference fit

Number		Interference fit		Fatigue life
T700-1	[%]	0	[Number]	45520
T700-2	[%]	0.5	[Number]	97769
T700-3	[%]	0.75	[Number]	241576
T700-4	[%]	1	[Number]	51663



(a) (b)

(c) (d)

Figure 2 (a) SEM images of surfaces of extrusion zones of hole with 0% interference fit; (b) with 0.5% interference fit; (c) with 0.75% interference fit and (d) with 1% interference fit

4. CONCLUSIONS

The interference fit actions have been investigated in the present experimental studies. The fatigue lives of the interference fitted specimens are increased when the interference fit size is increased from 0.5% to 0.75%. In contrast, the fatigue life of the specimen with 1% interference fit is lower than that of the same specimen with 0.75% interference fit. SEM observation reveal that the damage degree of interference fitted specimen is weaker than that for the neat fitted one.

ACKNOWLEDGEMENTS

Special gratitudes are due to the colleagues at Lab of Civil Aircraft Structure Testing.

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