An Experimental Investigation on Dynamic Performance of Interference-fit Composite Joints with Blind Bolt and High Lock Bolt

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Abstract. The experimental investigation were conducted in order to study the dynamic strength of the mechanically fastened composite joints, involving interference-fit joints with blind bolt and sliding-fit joints with high lock bolt. The joint type of the specimens researched was single-bolt, double-lap, which was a standard test configuration in ASTM for composite joints. Experimental results showed that the fatigue performance of the blind bolted joint was better than that of the high-locking bolted joint. The fatigue life of the blind bolted joints was 10-100 times higher than that of the high-locking bolted joint under the same cyclic stress, and the limit fatigue strength of the blind bolted joints was over 50MPa higher than that of the high-locking bolted joints.

Introduction

As the composite materials has become more and more widely used in the fields of aerospace, aviation and automotive, the fatigue performance of the whole plane and the fatigue life of composite structure have also attracted more and more attention. The mechanical structures of aircraft were mainly composed of high performance material structures (mostly composite structures) and advanced connection technology. However, the connection of composite materials was the weak link of composite structures. So in the design process of composite structure, researchers had not only satisfied with the dynamic analysis of the composite material itself, but also needed to pull enough energy in the dynamic performance research of composite structure.

A series of problems will be faced in the design of composite structure withstanding fatigue load, such as selecting the appropriate connection material and method according to the required fatigue performance, assessment of structural fatigue damage, designing of safe fatigue life to ensure the reliability of the connection and so on. Extrusion fatigue performance of mechanical joint is generally affected by the selection of R-ratio, fastener type, fastener preload/torque, fastener bolt-hole clearance, and environmental conditions. Chen [1] investigated the extrusion performance and the bolt torque / preload relaxation of bolted joints under thermal environment. The results showed that preload improved the failure strength and the fatigue life of specimen at room temperature. Counts [2] studied experimentally the effect of frequency, R-ratio, two composite materials, and thermal aging, and found that fatigue results were insensitive to frequency between 0.1 Hz and 10 Hz or 10,000 hours thermal aging.

Bolted or riveted joints have a significant effect on the failure of structures subjected to dynamical loading, and can cause local stiffness and damping altering. Starikov [3] experimentally studied the fatigue performance of carbon fiber/epoxy material panels joined by countersunk titanium joints and composite fasteners. Ibrahim [4] reviewed the role of joints parameter uncertainties and relaxation on the design and dynamic behavior of metallic and composite structure. Demelio [5] used shear and pull-out static and fatigue loading to study the performance of composite sandwich panels fastened by using blind fasteners and mechanical lock fasteners.

With the development of advanced technologies and manufacturing processes, the interference-fit joints were attempting to be used in composite structures for getting a better fatigue performance. There were scatter studies about the effect of static strength analysis [6], stress distribution [7]
interference-fit pin installation [8] on composite bolted or pinned joints. However, there are few experimental investigations about interference-fit with blind bolt, so a special experimental study had been carried out to investigate the dynamic bearing strength of a fastening system with blind bolt. In order to show the mechanical properties of the new fastening system under interference, the experiments were compared with sliding-fit with high lock bolt. This paper considered the effect of sliding-fit and interference-fit on the fatigue strength of the fastener structure.

Experimental Approach

Material and Specimen Preparation

The same composite material, T700/BP9916 Carbon Fiber Reinforced Plastic composite, was selected for compared specimens. Dimensions of 90×25mm and 5mm diameter fastener hole were adopted with all specimens. A double lap joint, with two 16-ply [45/0/-45/90]_2S laminates transferring load to a 20-ply [45/0/-45/90/0/0/45/0/-45/0]_3 main laminate, was used in all tests, since this provides the most stable configuration and minimizes the effect of bending in compression.

Two different fastener structures were used in the dynamic test: Fig.1 (a) showed the assembly progress of blind bolt of interference-fit. The drive nut was screwed to impel the nut into the expansion sleeve. The expansion sleeve was used to keep uniform interference to the hole. Expansion sleeve dimensions were for engineering reference only. When tightening torque of drive nut researched a certain set value, the screw and drive nut would break off; Fig.1 (b) was the high lock bolt (Ti6V4V) of sliding-fit. The type of assembly between bolt and hole is H9/h9. It was the common form of composite laminates on the aircraft.

Experimental Procedures

Fatigue bearing tests were performed using an INSTRON 8801 dynamic test machine. The loading cycle applied to all specimens was a constant amplitude sine wave with a stress ratio of R=-1. This fully reversed cycle was considered the most severe type of constant amplitude fatigue loading, and leaded to the shortest fatigue life. The test set-up was illustrated in Fig.2. An extensometer was used in order to measure the bolt-hole elongation for the single-bolt double lap bolted joint specimen. On the compressive stroke of the fatigue cycles, buckling of the joints was a strong possibility, especially in high bearing stress, so lateral supports must be used to prevent this.
Fatigue tests were conducted according to the ASTM D 6873 standard [9] at a room temperature of 20°C. A major factor to be considered was the potential for significant temperature increase, due to relative motion between the joint parts. If it became excessive, it would cause premature failure of the joint. To avoid this, frequencies between 2Hz and 3Hz were selected (higher frequencies were used for the joints tested at lower cycled loading). In addition, a cooling fan using compressed air directed onto the bolt was implemented, and the temperature of each bolt was monitored using infrared thermometer (Fig. 4). Bearing in mind that the temperature on the surface of the bolt is likely to be less than in the interior of the joint, the target maximum temperature for the bolt surface was set to 40°C, and test frequency was adjusted to try to maintain temperatures below this.

Results and Discussion

In order to compare the effect of different types of fasteners on the fatigue life of the structure, Fig.3 showed the S-N curves of the experimental results of the two fastened configurations (blind bolt fastener and high lock bolt fastener) under semi-logarithmic coordinates. As seen from the fitting S-N curves, the fatigue life of blind bolt was about 10 times higher than that of high lock bolt at the same cyclic stress level. When the cyclic stress level was \(\pm 50\% \sigma_{bru} (\pm 600\text{MPa}, \sigma_{bru} \text{ is the ultimate static bearing strength 1,200MPa [10]})\), the average fatigue life of the blind bolted structures was more than 100,000 times, while the fatigue life of the high-lock bolted joints was only 1,000 times, two orders of magnitude less than blind bolted joints. When the fatigue life was 1,000,000 times, the fatigue strength of blind bolt fastener researched 450MPa, which was 50MPa higher than high lock fastener.
Due to the fact that there was actually a slight amount of clearance between the bolt and hole during the process of connecting assembly, the fasteners under the action of the tension and compression load were continuously impacted on the wall at the beginning of the fatigue test, resulting in the cumulative impact damage around the hole of the composite laminates, and speeding up the failure of the composite structure. On the one hand, after the preparation of the test piece, the fastener was brought into close contact with the load hole, that is, the initial actual nail gap is zero. Only after some fatigue cycles, the hole of composite material could be damaged and produce deformation. Then the gap of bolt and hole generated and increased until the appearance of the impact damage, which was relative to the high lock bolt with H9/h9 tolerance. Blind bolt with 0% interference largely delayed the impact damage under cyclic loading. On the other hand, the tiny burr layer of the laminates was compressed to form a layer of micro burr elastic layer after the assembly of 0% interference fit so that the stress around the hole was redistributed and the stress concentration coefficient would be reduced to a certain extent. For the above two aspects, the blind bolt with 0% interference fit could improve the fatigue life of the composite joints rather than the high lock bolt with sliding.

**High Lock Bolted Fasteners**

The fatigue test of high lock bolted fastener was carried out under the cyclic loading level of 30%~50% $\sigma_{bru}$. With the increase of fatigue cycle, the corresponding deformation of composite hole was obtained by using extensor. In fig.4, the increase of hole deformation was linearly related to the number of cycles at the initial small number of cycle stages, and with the number of cycles increasing, the amount of hole deformation changed from linear to exponential. This was because as the diameter of the nail hole increased, the impact damage on the inner wall of the nail hole would increase.

![Figure 4. Fatigue curves of high lock bolted fastener.](image)

**Blind Bolted Fasteners**

The fatigue tests under different cyclic stresses were also carried out for the blind bolted fastener structure. Figure 5 showed the relationship between hole deformation and cycle times under different cyclic stresses. It can be observed from the table, the hole deformation was divided into two stages, linear segment in the early period and index in the late period. The difference form high lock bolt was the longer and flatter linear segment.
Figure 5. Fatigue curves of blind bolted fastener.

Conclusions

An experimental study had been carried out to investigate the effect of several factors (the types of bolts, the sizes of interference fit, different materials of laps, and stacking sequences of main laminates) on the fatigue behavior of bolted joints in composite laminates. The static ultimate bearing strengths of neat fit and interference fit were obtained through static tensile tests. The relationship between S-N curves and failure mechanism were examined. Thus, the following results were concluded:

1) The fatigue performance of the blind bolted joint was better than that of the high-locking bolted joint. The fatigue life of the blind bolted joints was 1-2 orders of magnitude higher than that of the high-locking bolted joint under the same cyclic stress, and the limit fatigue strength of the blind bolted joints was over 50MPa higher than that of the high-locking bolted;

2) Under the condition that the cyclic stress was ±55%σbru and the size of interference fit was 1.8%, stacking sequences of main laminates had no obvious effect on the fatigue life of the nailing interference joint structure.

References


