Research on failure strength of composites bolted joints under temperature condition

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Abstract

The method of predicting the strength of laminated composite bolted joints under temperature condition was derived, which was based on the progressive damage analysis method, and took into consideration the effects of temperatures on the composite materials properties and the total stresses. The simulation analysis of the failure modals and failure strengths of the bolted joints under 22℃、150℃、230℃ and 310℃ was conducted. The simulation results was compared with the experimental results , and the maximum error of predicted strength value was 6.32%, which shows that the method of predicting the strength of composite bolted joints and the experiment results on composite laminate bolted joints agrees well.

Keywords: Temperature condition; laminated composites; bolted joints; progressive damage; strength

Introduction

Composites are widely used in aeronautical structures, and it is difficult to avoid various connection problems in complex aviation structures. Bolt connection can withstand high load, easy loading and unloading, which has become the most important and widely

connected. However,the bolted connection structure will destroy the continuity of the composite fiber, resulting in the bearing capacity decreased, leading to premature failure of the structure, and thus the strength of the composite bolt connection structure has become a hot topic of concern to scholars. At the same time, the aviation structure often works in different temperature environment, when the resin-based composite structure in high temperature environment, the mechanical properties of the material will be reduced to varying degrees. Therefore, it is very important to study the mechanical properties of the resin-based composite bolts in the temperature environment.

Based on the above analysis. This article experimental study on the tensile strength and damage mechanism of the composite structure of composite laminates in four temperature environments was carried out. And based on the method of gradual accumulation of damage, considering the establishment of a method for forecasting temperatures of the composite tensile strength bolted joint, which method takes into account the influence of stress and temperature mechanical properties of the basic material. In order to improve the use of the forecasting method, the relationship between the basic mechanical properties and the temperature of the composite material in the range of 22℃~ 310℃was established. The results show that the simulation results are in good agreement with the experimental results. The results show that the simulation results are in good agreement with the experimental results.

Experimental approach

In order to compare the effects of different ratio of the width with hole pore and temperature on the failure mode of bolted connections. Two kinds of the ratio of the width with hole pore composit laminates of T300/BMP316, which were in the order of $[45/-45/90/0/-45/0/45/0/90/0]_{s,}$, were used for this investigation.The specimens were exposed to different temperature environments, and were numbered by T-E-W-Z where T was the tensile

strength specimen,E was the pore size,W was the test temperature, Z was different serial numbers of the same ratio of width with hole pore.

Table 1 Specimens parameters

Ratio of width with hole pore	pore size / mm	(length x width) / mm	temperature condition /℃	quantity / pieces
3	8	160x24	22	3
3	8	160x24	150	3
3	8	160x24	230	3
3	8	160x24	310	2
4	6	160x24	22	2
4	6	160x24	150	3
4	6	160x24	230	3
4	6	160x24	310	2

(a)T-8-RT-1

(b)T-8-150-1

(c)T-8-230-1

(d)T-8-310-1

Fig.1 Fracture of bolted joint

Taking the photograph of the damage test specimens, which the ratio of the width with hole pore is three,to analyze the failure mode,as shown in Fig.1.

Tensile failure, crushing failure,shear failure are the basic failure modes of the bolted joints at room temperature. It can be seen from Fig.2, that tensile failure is the main failure mode of the bolted joints at 150℃ and 230 ℃, the shear failure is the main failure mode at 310℃, and the extrusion deformation occurs at the edge of the hole, and the damage is extended to the joint end unit, indicating that failure mode of bolted connections at room temperature is the same with in a high temperature environment,but the ultimate failure mode at different temperatures are different, tensile failure mainly at 150 ℃ and 230℃, the main failure mode of the joint is shear failure at 310℃, which indicates that the high temperature has an important effect on the final failure mode of the bolt joint.

Example analysis

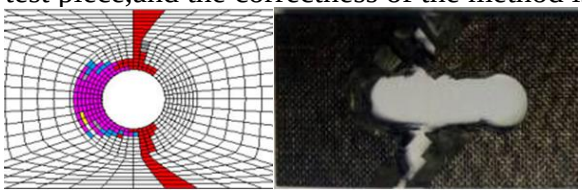
In this paper, the corresponding static tensile experiments were conducted at 22℃, 150℃, 230℃, 310℃, to valitate the prediction results. The results were compared shown in Table 2.

Table 2 Comparison of tension ultimate failure strength of bolted joints

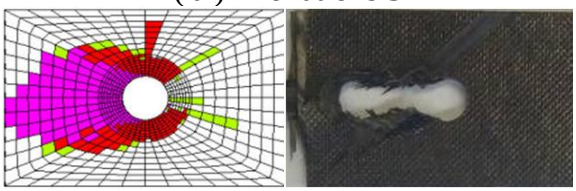
The ratio of the width with hole is three				The ratio of the width with hole is four			
temperature /℃	Experimental value /MPa	Predicted value /MPa	error%	temperature /℃	Experimental value /MPa	Predicted values /MPa	error/%
22	140.71	146	-3.76	22	153.38	158	-3.01
150	100.64	107	-6.32	150	146.84	149	-1.47
230	88.26	92	-4.24	230	141.66	146	-3.06
310	81.83	86	-5.10	310	90.42	95	-5.07

It can be seen from Table 2, that the maximum error of the predicted strength value is -6.32%,and the calculation results of each intensity are too large, which is a risky prediction.

This article only compares the damage fracture of failure mode simulation with the actual test damage fracture only of two different ratio of width with hole pore at 230℃,as show in Fig.3,From it can be seen the damage projection pattern of the bolt joint is consistent with the final failure result of the test piece,and the correctness of the method is proved.



(a) The ratio is 3



(b) The ratio is 4

Fig.2 Final failure results of experiment and simulation of jointed bolts with two different ratios under 230 °C

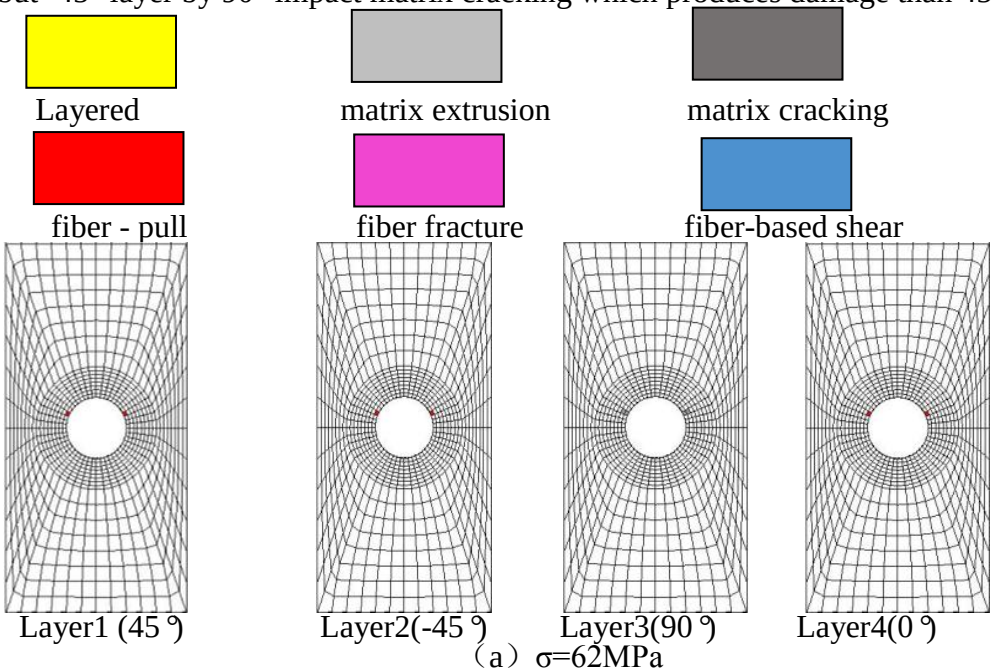
The study shows that, the injury in two groups of specimens are similar in Table 2, in order to save space, this article only take the bolted joint with the ratio of 3 at 230℃ as example to analyse the initernal damage propagation law and form of the bolted joint laminates,selecting the first four layers of the laminates(layer -45 °,0 °,45 °,90 °) as represent during the analysis process,as shown in Fig.3.

It can be seen from Fig. 3 (a) that when the load is increased to 62MPa under the uniform tensile load , the 0 °layer has the fiber breaking damage, and the damage position is at the maximum stress on the left and right sides of the connection hole. In this tensile load,the 90 °layer of the substrate cracking damage appeared more obvious expansion, 45 °and -45 °layer appeared obvious fiber breaking damage, mainly because the 45 °and -45 °layer is the matrix,And the fiber co-bearing, although the matrix failure to lose the carrying capacity, but because the fiber can still be carried to make the damage unit still has a certain carrying capacity, so with the increase in load, the original matrix cracking damage units have appeared fiber break damage. In addition, the occurrence of other substrate damage caused the redistribution of the stress field inside the laminates, which made the stress concentration more obvious, which further promoted the fracture of the bearing fiber. As the load increases further, the damage of each layer begins to extend toward the end of the joint and in the width of the plate. Fig.3(b) shows the specific damage forms and the expansion of the first four layers when the load reaches 92 MPa . At this time, the 45 °layer mainly occurs in the fiber fracture, matrix cracking and matrix cracking - fiber breakage form damage; -45 °layer occurred mainly in fiber fracture and matrix cracking, matrix cracking - fiber fracture, matrix cracking -fiber damage - fiber-based shear and other damage coexist damage; 90 °layer mainly occurred in the matrix cracking and fiber fracture, accompanied by fiber-based shear, matrix cracking – fiber fracture and other damage; 0 °layer mainly occurred

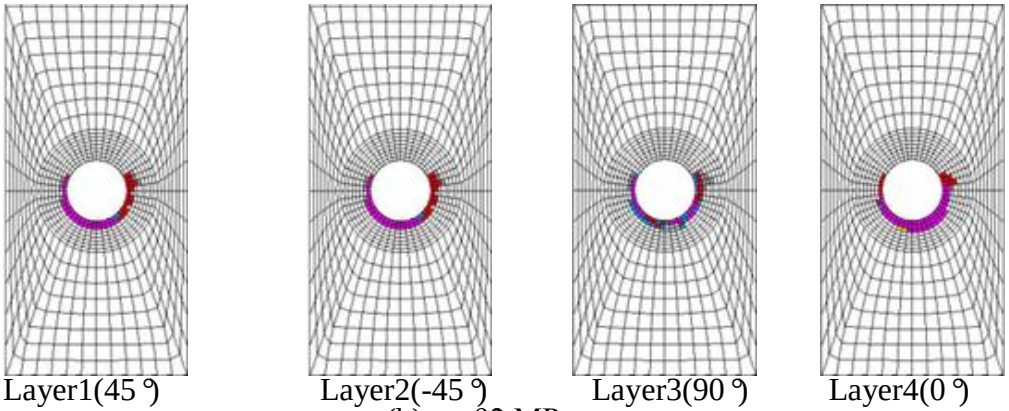
in the fiber fracture, fiber fracture - fiber-based shear damage, but also occurred a small amount of stratification and matrix cracking damage.The damage pattern of the -45 °layer unit is more diversified than that of the 45 °layer, mainly because the -45 °layer is adjacent to the 90 °layer. When the 90 °layer is damaged, the adjacent -45 °layer have a certain effect on the shear effect;

Fig.3(c) shows that when the tensile load increases to 137Mpa , the first four layers of damage to further expand the situation , then you can see the pavement damage are obvious expansion , mainly along the bolt extrusion direction ,the damage is already extended to the dense area of the dividing grid.

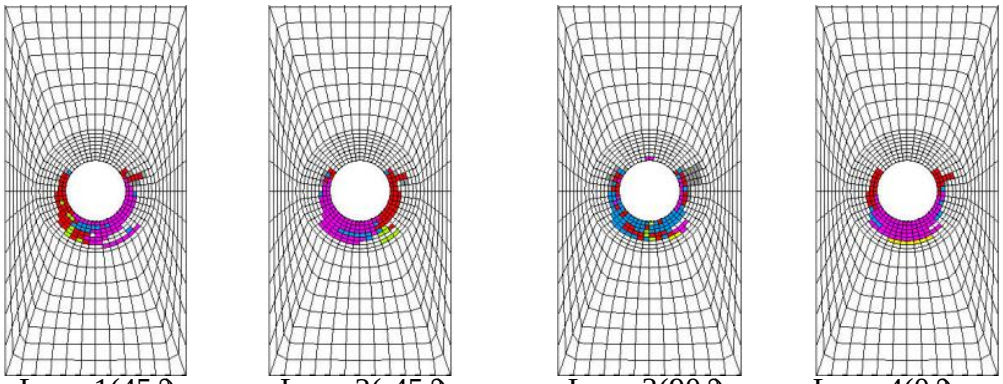
Fig.3(d) shows when the tensile load is increased 146Mpa specifically injury before breakage when four failure modes, it can be seen, 0 ° Layer, ± 45 °and 90 °layers have been extended to damage the plate width boundary,which indicates that the bolt failure has occurred in the final failure damage, the main form of damage is the tensile damage, which is consistent with the test results; 0 °layer occurred in the form of fiber breakage damage occurred at the same time in the joint extrusion;The damage of the 90 °layer is more, mainly due to the matrix cracking and matrix damage - fiber-based shear damage extended to the joint board wide boundary, also accompanied by a certain hierarchical fracturing and matrix - fiber-yl shear - fiber breaking pressure damage; 45 ° primary failure mode of the fiber layer is pulled off to the damage propagation in the sheet width at the boundary, while the side of the bolt holes pushing region in the 45 °direction breaking pressure significantly damage the fiber, also accompanied by some fiber damage shear; -45 ° layer when the final destruction occurs, and the damage in the form of 45 °substantially uniform layer, and with Vera off the main failure mode, in the -45 °direction hole pushing region also produces a more severe fiber damage off pressure, but -45 °layer by 90 °impact matrix cracking which produces damage than 45 °.



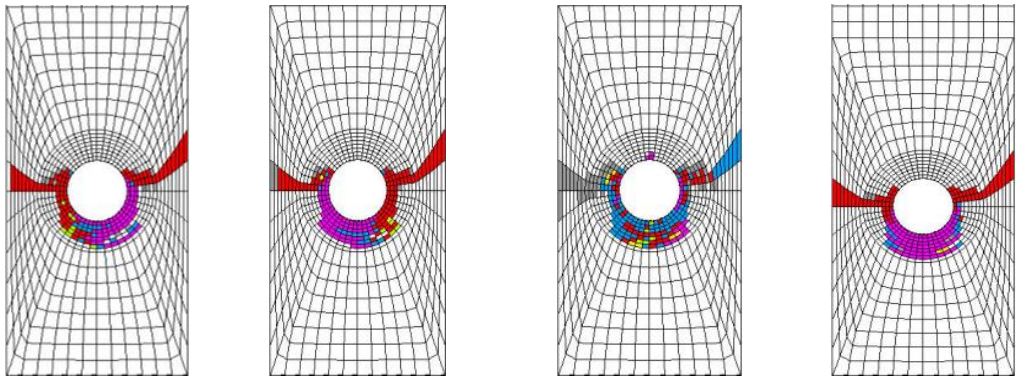
（a）σ=62MPa



(b)σ = 92 MPa



（c）σ=137MPa



(d)σ = 146 MPa

Fig.3 Progressive damage of composite bolted joint (230 °C)

Conclusion

The tensile strength of two kinds of bolt joints with different width ratio was studied at room temperature, 150 ℃ , 230 ℃ and 310 ℃.The experimental results show that with the same width ratio,the increase of the temperature of the bolt joint strength decreases gradually, and the higher the temperature, the greater the decrease. The decrease static load strength of bolt joint at 15℃， 230℃,and 310℃ is 4.26%，7.64%,and 41.05%(ratio is 3);28.48%,37.28%and 41.84%(ratio is 4),indicating that the temperature plays a very important influence on the strength of the joint bolt; at the same temperature,the larger ration the strength value of the joint is smaller,and the smaller pore size, the more obvious the stress concentration at the joint, the lower the breaking strength.

In this paper, the experimental study on the tensile strength and damage mechanism of the composite structure of laminates with four kinds of temperature environment is carried out. Based on the method of progressive damage analysis method, the method of predicting the tensile strength of composite bolts with temperature environment is established. The effect of temperature on the stress and the basic mechanical properties of the material is taken into account. In order to improve the use of the forecasting method, the relationship between the basic mechanical properties and the temperature of the composite material in the range of 22 ℃ ~ 310 ℃ was established. The results show that the simulation results are in good agreement with the experimental results.

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