STUDY ON CRASH OF COMPOSITE FUSELAGE WITH STRAIN RATE EFFECT

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ABSTRACT

Composite material has been widely applied to design and manufacturing of aircraft. The energy absorption mechanism, damage and failure criteria of composites are very different from metals, and most study on crash of aircraft has focused on metal fuselage. Therefore, the study on crash of composite fuselage poses a challenge. In past studies, the simulation of crash of composite fuselage rarely considered the strain rate effect. In our work, we developed dynamic property test of composite and obtained its constitutive model and strength under high and medium strain rate. Based on the test data, we validated our simulation process by building block approach and analysed the crash of composite fuselage with strain rate considered.

1 INTRODUCTION

The study on crash of civil aircraft experienced stages from estimation crashworthiness of metallic structure to composite structure. The energy absorption mechanism, damage and failure criteria of composites are very different from metals, and most study on crash of aircraft has focused on metal fuselage [1]. Therefore, the study on crash of composite fuselage poses a challenge.

Many researchers have worked on the damage and failure mechanism of composites and designed composite structures for energy absorption [2-4]. Simulation methods also have been developed to predict dynamic response of aircraft under high velocity impact [5-8]. However, the past studies on crash of composite fuselage rarely considered the effect of strain rate. The strain rate may play an important role during the crash process, especially, when the volume proportion of matrix in the composite structure is high.

2 EXPERIMENT

Split Hopkinson pressure bar (SHPB) is employed to obtain the dynamic properties of fiber reinforcement composites. The load vs. displacement history of composites with different impact velocities were obtained in the experiment.

Since the testing for dynamic properties of composites has not been standardized , we designed a series of specimens to test the in-plane tension, in-plane compression, out-of-plane tension, out-of-plane compression and shear properties of composite laminates under high (about 10^3/s) or medium (about 10^2/s) strain rate (Figure 1). The material used in the test is composed of carbon fiber reinforced composite with toughened epoxy resin. There are 20 specimens of each group for impact test. To obtain the effect of strain rate, we also carried out quasi-static test of in-plane tension, in-plane compression, out-of-plane tension, out-of-plane compression and shear with 10 specimens for each stack. These quasi-static tests were conducted according to ASTM standards. Since the dynamic performance of joints is also important in crash process of composite fuselage, the tension and compression test on joints of laminates was also performed (Figure 2).

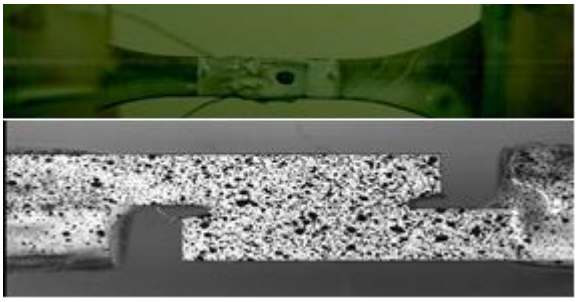


Figure 1: Composite specimens for dynamic performance test.

Figure 2: Tension test on laminates with joints under high velocity impact.

The failure modes of some specimens are shown in Figure 3. From experiment results we find that these composite specimens suffered strain rate hardening with high velocity impact, especially for the mechanical properties governed by matrix, such as out-of-plane compression, which is shown in Figure 4.

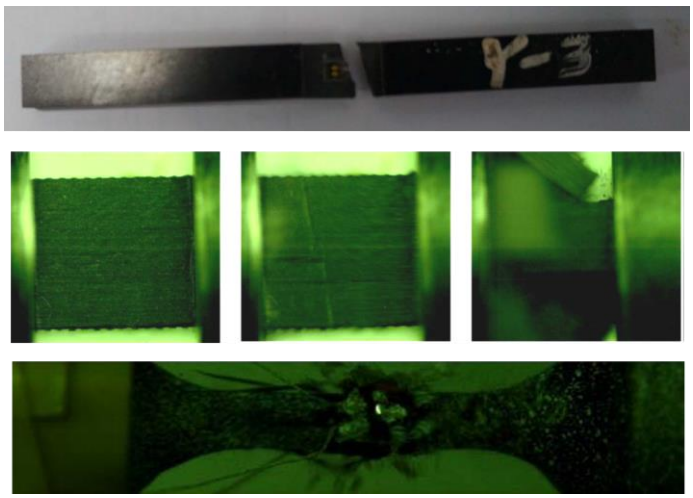


Figure 3: Failure modes of composite specimens under high velocity impact.

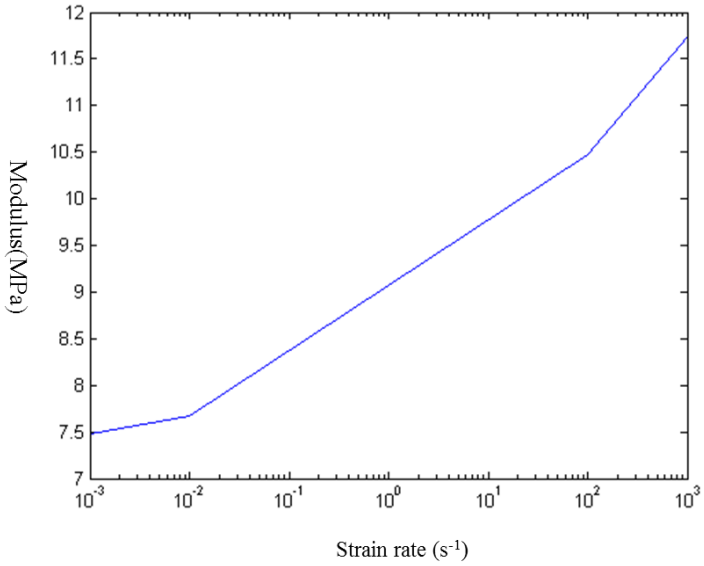


Figure 4: Modulus vs. strain rate obtained from out-of-plane compression test.

3 MODEL VALIDATION

The simulation process of crash of composite fuselage is very complex and difficult to validate without corresponding test data. In order to validate the simulation method by building block approach, we started by simulating the high velocity impact process of joints in composite laminates. In the FEM model with cumulative damage, a subroutine VUMAT of composite is applied to introduce the damage criteria [9-10].

The quasi-static tension test process is simulated by FEM. We compared the simulation results and test data, and it shows that tension strength and bearing strength predicted by FEM is similar with those obtained from the experiment. Moreover, the pink load also agrees with the experimental results (Figure 5). The accuracy of subroutine VUMAT of composite is validated.

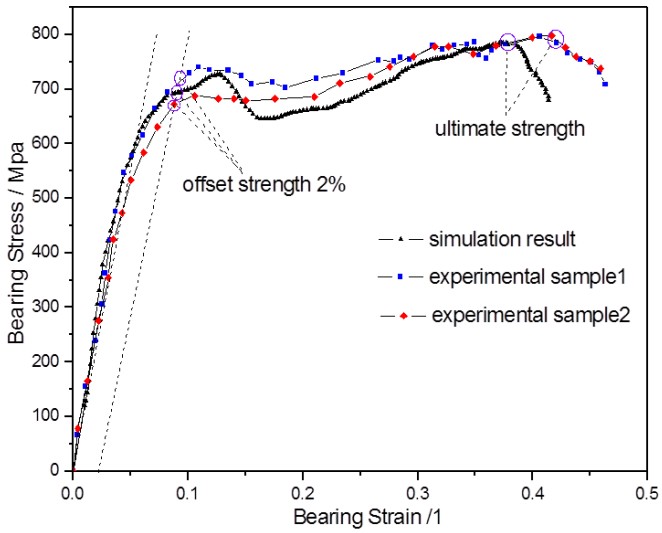


Figure 5: Bearing stress varies with bearing strain.

We also presented the damage evolution process obtained by simulation in Figure 6. The tensile load induced failure can be divided into five typical stages. In the first stage that from *t0* to *t1* moment,

the contact force rapidly increases in the loading process, the matrix in lapping zone starts to failure. In the second stage, as from *t1* to *t2* moment, the matrix damage increases in the lapping zone, delamination occurs in the adjacent area of the hole. The energy slowly lost while the contact force slowly increases during this stage. In the third stage, as from *t2* to *t3* moment, severe damage occurs in the laminate, and the dissipation of energy slowly grows since it is induced by the buckling of several plies in the laminate. In the fourth stage, from *t3* to *t4* moment, the laminate damages in large area with plies buckling induced by bearing stress in the hole. After *t4* moment, namely the fifth stage, buckling happens in most of the plies, the load-carrying ability of laminate will decline sharply.

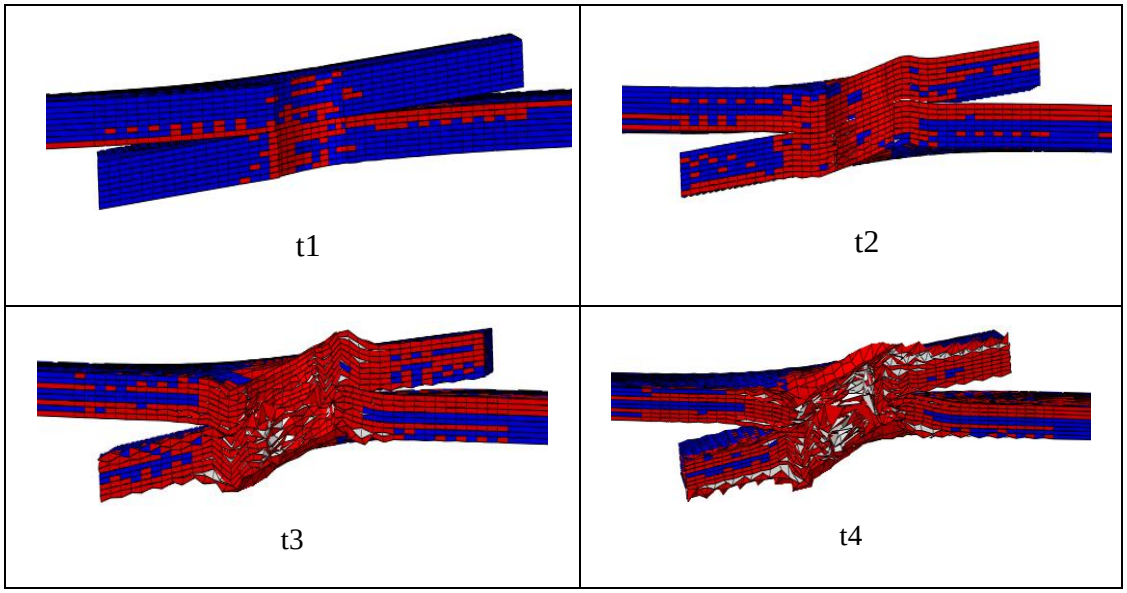
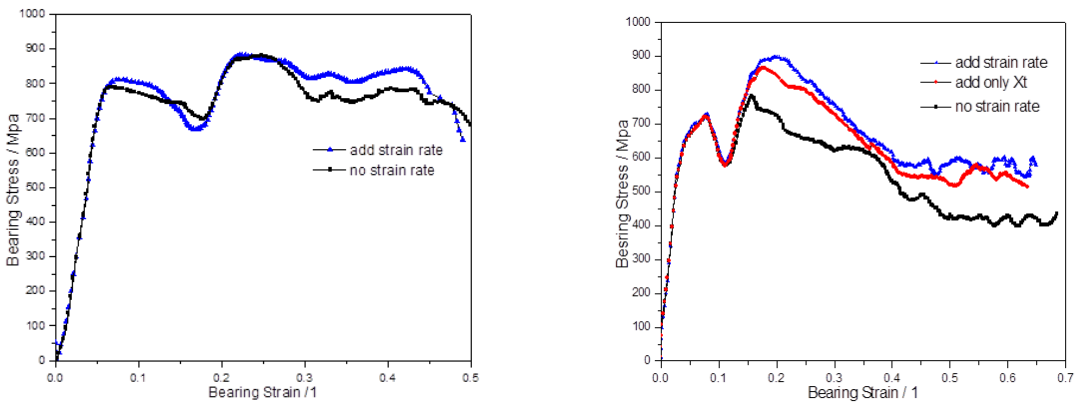


Figure 6: Bearing stress varies with bearing strain with and without strain rate effect.

Based on test data, the tension and compression of joints under high impact velocity is also simulated. First, the constitutive relation of composites with different strain rate is formed accordingly. Both the simulation and experimental result shows that the tension of joints is not sensitive to strain rate effect. In contrast, the compression result is sensitive to strain rate (Figure 7).



a) Tension b) Compression

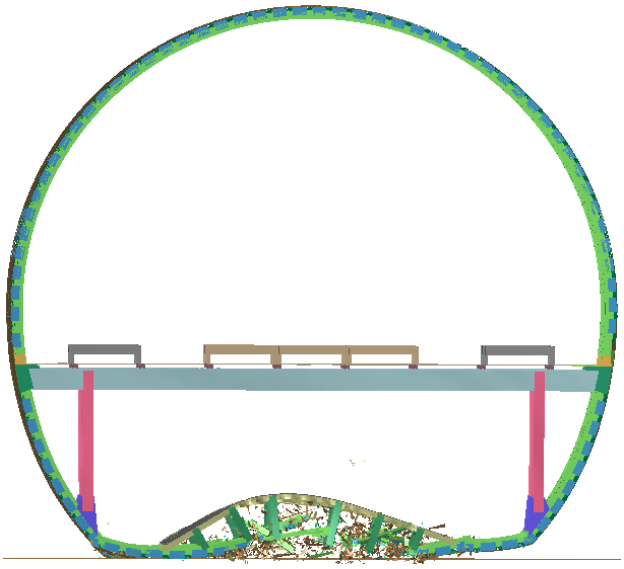
Figure 7: Bearing stress varies with bearing strain with and without strain rate effect.

4 SIMULATION OF FUSELAGE CRASH

After the validation of the model is validated, we simulated the crash process of composite fuselage. A fuselage component with three frames was chosen, which represents the state of the whole fuselage in the crash process. In the model, the frame and skin are composed of composites, and the passenger deck honeycomb core material while other components aluminum. A crash velocity of V=7m/s was set in the simulation.

Since the purpose of study on crash is to protect the safety of passengers, we focused on the impact load on passengers. We chose two points that on side seat and center seat to investigate their acceleration responds in the crash process of the fuselage.

Figure 8 is the result of composite fuselage crash and the dynamic response of seats. It shows that the acceleration peak is different with and without strain rate considered.



Crash of composite fuselage

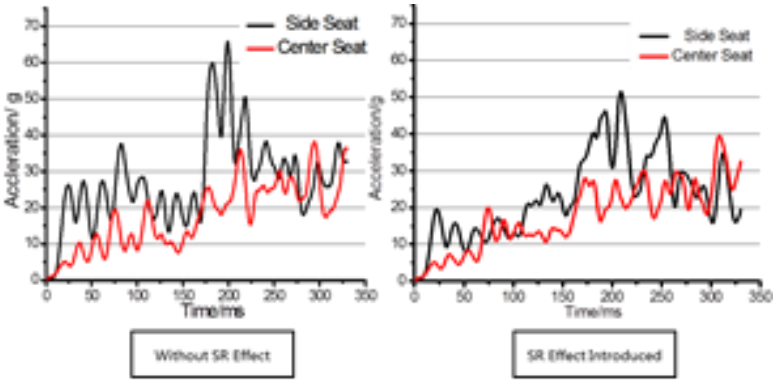


Figure 8: Crash of composite fuselage and seat's dynamic response of crash with and without strain rate considered.

5 CONCLUSIONS

In this paper, a series of tests for laminates under high and medium strain rate were performed with the constitutive model and strength obtained. Based on the test data, we validated our simulation process by building block approach and analysed the crash of composite fuselage with strain rate considered. It shows that the strain rate effect should be considered in the crash simulation process.

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