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Crash analysis of composite airplane fuselage with strain rate effect

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ABSTRACT

Composite material has been widely applied to civil aircraft on primary structures including both wing and fuselage. 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 performed dynamic property test for composite material, derived its constitutive model, and obtained its 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 started from crashworthiness estimation of metallic structures. In recent years, composite material has been widely applied to primary structures on passenger jets including both wing and fuselage. The energy absorption mechanism, damage and failure criteria of composites are very different from metals. Most studies so far on crash of aircraft structures has been focused on metal fuselage. Therefore the study on crashworthiness 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 (Wiggenraad et al., Hou et al.). Simulation methods also have been developed to predict dynamic response of aircraft structures under high velocity impact (Johnson and Pickett, Deletombe et al.). 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.

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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 (Fig. 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.

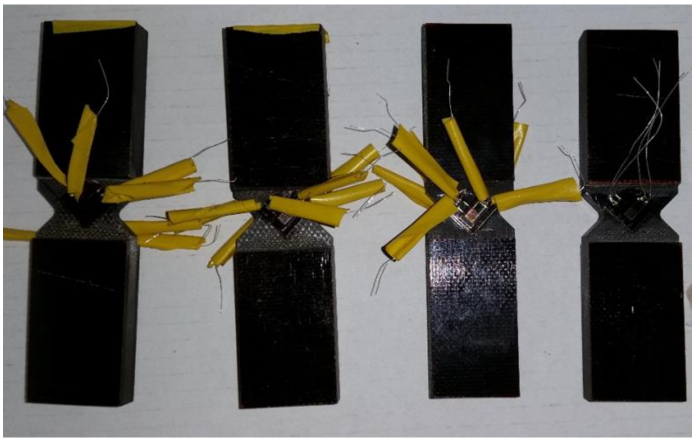


Fig. 1 Composite specimens for dynamic performance test.

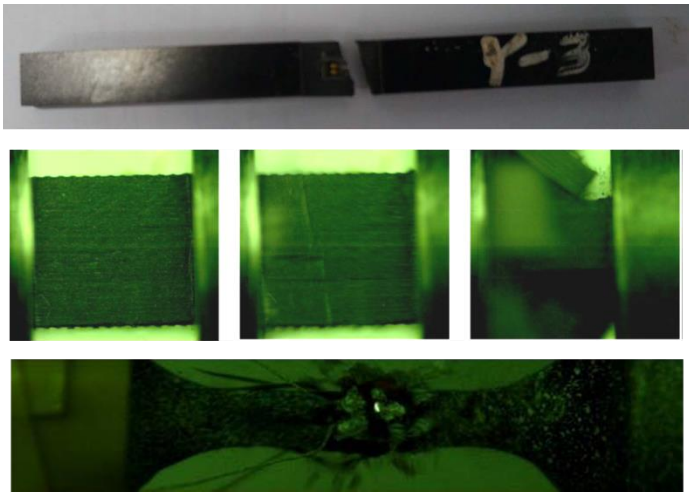


Fig. 2 Failure modes of composite specimens under high velocity impact.

The failure modes of some specimens are shown in Fig. 2. 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.

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 (Camanho and Davila, Benzeggagh and Kenane).

The quasi-static tension test process is simulated by FEM. We compared the simulation results with test data, and it shows that tension strength and bearing strength predicted by FEM is similar with those obtained from the experiment. Moreover, the peak load also agrees with the experimental results (Fig. 3). The accuracy of subroutine VUMAT of composite is validated.

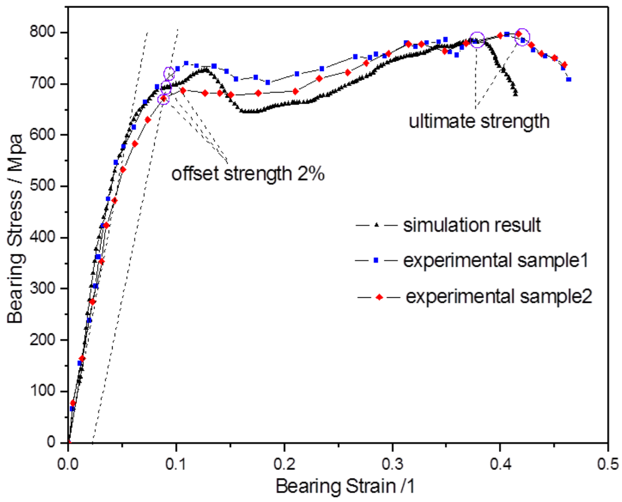


Fig. 3 Bearing stress varies with bearing strain.

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 results show that the tension of joints is not sensitive to strain rate effect, but in contrast, the compression result is sensitive to strain rate (Fig. 4).

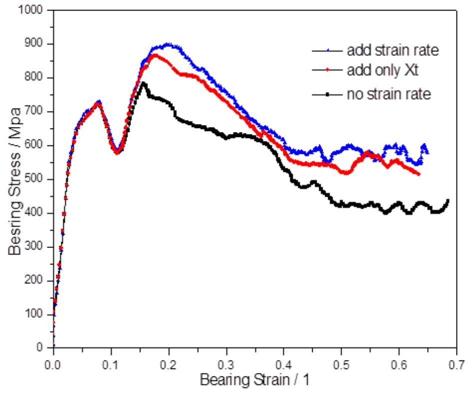


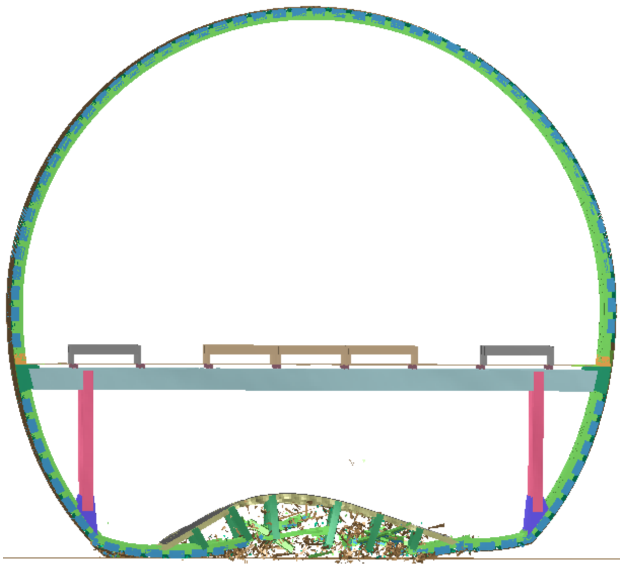
Fig. 4 Bearing stress varies with bearing strain with and without strain rate effect.

4. SIMULATION OF FUSELAGE CRASH

After 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 while other components are composed Aluminium. 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.

Fig.5 is the result of composite fuselage crash and the kinetic energy curve. It shows that the kinetic energy decreases differently with and without strain rate considered.



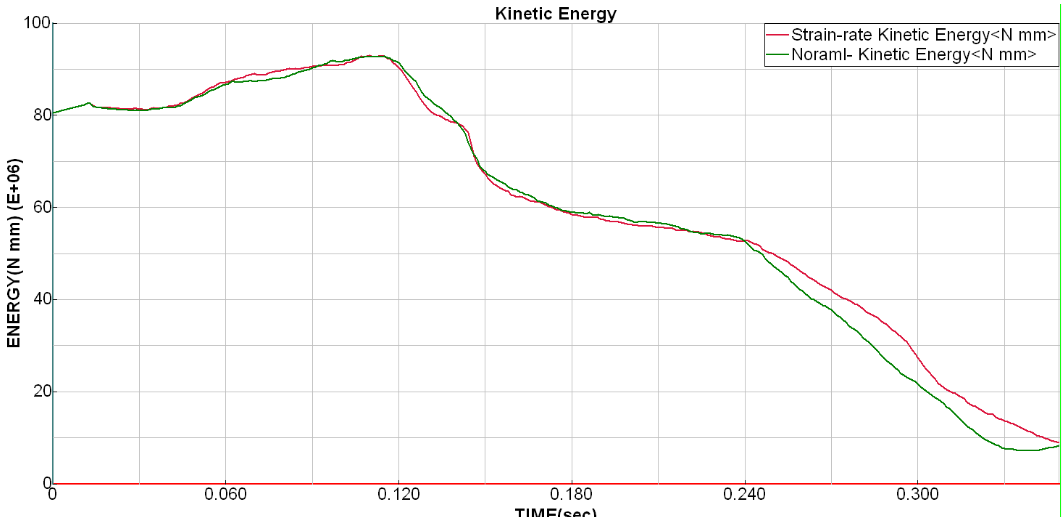


Fig. 5 Crash of composite fuselage and kinetic energy curve during crash with and without strain rate considered.

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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