ESTIMATION OF RESIDUAL STRENGTH DISTRIBUTION OF COMPOSITE STRUCTURE WITH IMPACT-INDUCED DAMAGE

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1 General Introduction

One of the main drawbacks of composite materials is that they show a large variation of properties mainly in strength due to their inhomogeneity [1]. Thus, many pieces of research have statistically analyzed the strength of composite materials [2]. However, when impacted composite structures are loaded, they may produce different statistical behaviors due to the impact damage.

To address this, the authors have analyzed the statistical properties of residual strength of composite structures subjected to low velocity impact [2,3]. Unfortunately, the approach does not take into account the distribution of flexural strength in unimpacted materials which may affect the distribution of residual strength, but does use only the residual strength itself.

This paper develops a new approach to predict the statistical distribution of residual strength of composite materials subjected to low velocity impact. The model was derived from the Weibull parameters for strength of unimpacted composite materials, and strength reduction behavior of impacted materials. The model was experimentally verified by using an experimental program for honeycomb core sandwich structures.

2 Experiments

2.1 Materials and Specimen

The cell size and density of honeycomb core (Aerocell CACH 1/8-3.) are 3.2mm and 48kg/m^3, respectively. The thickness of the core material was 10mm and 20mm. The facesheets were unidirectional eight-ply carbon/epoxy (TBCarbon CP200NS) laminates obtained from a prepreg with a thickness of about 0.2mm. Their stacking sequences are [$0_2/90_4/0_2$]. The fabricated sandwich structures were then cut into panels with a width of 40mm and a length of 250mm. We used the following notation: SC10 for the structure with a core thickness of 10mm and SC20 for the structure with a core thickness of 20mm.

2.2 Impact and Flexural Tes

The Dynatup 9250HV machine was used to conduct the low velocity impact tests. The panels were round-clamped with an opening of 76.2 mm-diameters. The radius and mass of the hemispherical impactor were 6.35mm and 6.45kg, respectively. After being impacted, three-point flexural tests were conducted by a universal testing machine (Instron 5581). The sandwich panels were simply supported on 25.4mm diameter rollers with a span length of 160mm, keeping the impacted surface downward. The crosshead speed was 3mm/min.

3 Results and Discussion

3.1 Statistical Approach for Residual Strength

Experimental residual strength data [3,4] on composite materials indicate that residual strength σ_R after low velocity impact is a decreasing function of incident impact energy E_i. Assuming that the residual strength σ_R can be expressed in terms of the ultimate strength σ_0 and function of impact energy, one obtains an equation,

$$\sigma_R = \sigma_0 \cdot f(E_i) \tag{1}$$

in which $f(E_i)$ is a function of the incident impact energy and describes the strength reduction behavior. Eq. (1) expresses the residual strength of materials subjected to the incident impact energy E_i, in terms of the ultimate strength σ_0 and the impact energy.

It is resonable to assume that the statistical distribution of the ultimate strength follows a 2-parameter Weibull distribution [12];

$$F_{\sigma_0}(x) = P[\sigma_0 \le x] = 1 - \exp\left[-\left(\frac{x}{\beta}\right)^{\alpha}\right] \qquad (2)$$

in which $F_{\sigma_0}(x)$ is the distribution function denoting the probability that the ultimate strength σ_0 is smaller than a value x. Also, α and β are the shape and scale (characteristic length) parameter, respectively.

Combining Eqs. (1) and (2), one obtains

$$F_{\sigma_R}(x) = 1 - \exp\left[-\left(\frac{x}{\beta \cdot \{E_{th}/E_i\}^m}\right)^{\alpha}\right]; \; E_i \ge E_{th} \qquad (3)$$

And, they are different from those of the unimpacted composite materials as following.

3.2 Experimental Verification

Theoretical predictions by using Eq. (3) are plotted in Fig. 1 as dotted lines (failure probability of 90% and 95%) and experimental data as circles. Predicted results describe the experimental results well.

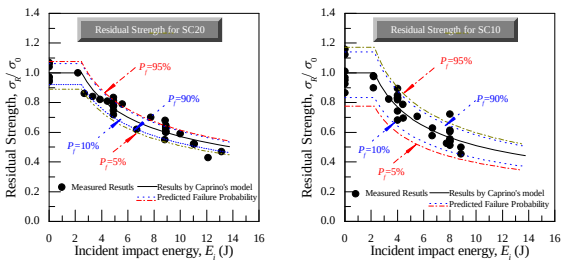

Fig. 3 Distribution of residual strength

The theoretical predictions at given energy levels were made and then comparisons were made between the predicted (simulated) and experimental (measured) results for SC10 and SC20 panels (Figs. 2 and 3, respectively). Here the measured results were obtained by directly applying the 2-parameter Weibull distribution to the seven residual strength data at given energy levels (4.0 and 8.0J for SC10 panels, 4.9J and 8.9J for SC20 panels). The simulated distributions compared well with the measured distribtions for both the SC10 and SC20 panels. The proposed approach was, therefore, useful to predict the residual strength distribution under any incident impact energy level.

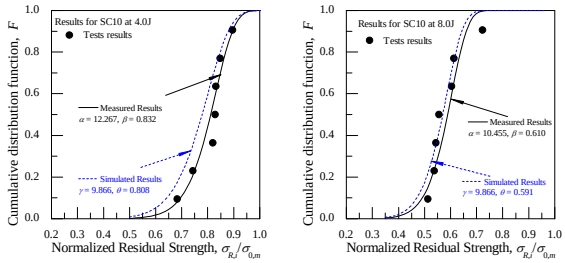

Fig. 2 Simulated distribution of SC10 panels

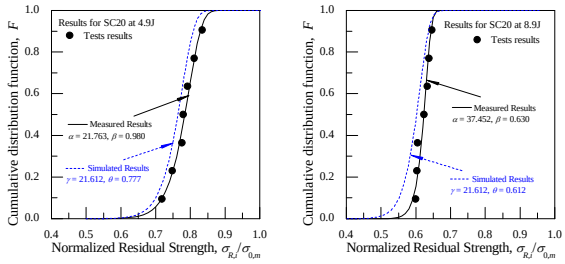

Fig. 2 Simulated distribution of SC20 panels

4 Conclusions

This paper provides a new approach to predict the statistical distribution of residual strength in impacted sandwich structure. By using experimental program, this approach was found to be capable of predicting the distribution of residual strength at any impact energy levels.

References

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