Simple Approach for Statistical Distribution of Residual Strength in Composite Structure subjected to Low Velocity Impact

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INTRODUCTION

One of the main drawbacks of composite materials is that they show a large variation of properties mainly in strength due to their inherent flaws [1]. Thus, introducing the normal or Weibull distribution, many pieces of research have statistically analyzed the strength of composite materials [2,3]. However, when composite structures with impact-induced damage are loaded, they may produce a quite different statistical behavior of residual strength due to the inherent flaws and impact damage. A little attention has, however, been paid to the statistical distribution of residual strength of impacted composite materials.

The paper deals with development of 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 properties of strength in unimpacted composite materials and residual strength of impacted materials. The model was verified experimentally by use of honeycomb core sandwich structures.

EXPERIMENTAL PROCEDURE

The Nomex® honeycomb core (Aerocell CACH 1/8-3.) is of high strength, non-metallic honeycomb manufactured with aramid fiber paper and its cell size and density are 3.2mm and 48kg/m^3, respectively. The thickness of core material is 10mm and 20mm. The facesheet is unidirectional eight-ply carbon/epoxy (TBCarbon CP200NS) laminates obtained from a prepreg having a thickness of about 0.2mm. Their stacking sequences are [$0_2/90_4/0_2$]. The material properties of the facesheet were determined from tensile test according to ASTM D-3039-00 [4] and the material properties of core material, are shown in Table 1.

The Dynatup model 9250HV impact testing machine was used to conduct the low velocity impact tests. The drop-weight testing machine consists of a drop tower equipped with an impactor, which has a hemispherical nose, and a variable crosshead weight arrangement, high bandwidth DSP (Digital Signal Processing) electronics, self-identifying load cells, and Impulse™ control and data acquisition software. The panels were round-clamped with the 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 an universal testing machine (Instron 5581).

RESULTS AND DISCUSSION

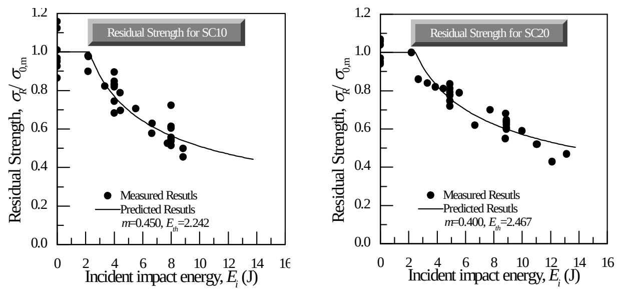
To identify the statistical distribution of residual strength in the impacted composite structures, the distribution of strength in the unimpacted structures should be firstly assessed. For this, seven panels are tested statically under flexural loading and the 2-parameter Weibull distribution. For the SC10 structure, a shape parameter and a characterisc

Table 1. Mechanical properties of facesheet laminates and Nomex honeycomb core

Laminates	E_{xx}(GPa)	E_{yy}(GPa)	E_{xy}(GPa)
Carbon/epoxy laminates	127.53	7.85	0.34
Thickenss (mm)	Density (kg/m^3)	Shear modulus (MPa)	Shear strength (MPa)
10 & 20	48.0	19.3	0.58

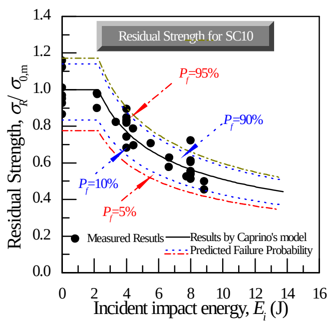
length have been obtained.

Next, to identify reduced strength of sandwich panels with impact-induced damage, three point flexural tests were conducted for the impacted sandwich panels subjected to the incident impact energy in the range of 2.18-8.85J for SC10 and 2.19-13.1J for SC20, respectively. The residual strength data, normalized by the mean strength of the unimpacted sandwich panels, are plotted against impact energy in Fig. 1. From figure, the residual strength is not influeced by the incipent impact energy up to some energy level (2.242J for SC10 and 2.467J for SC20): thus, this level can be defined as strength threshold energy, which is the minimum energy to cause strength reduction in structures. Above these energy levels, the residual strength is rapidly reduced with the incident impact energy and reaches at about 50% of strength in unimpacted sandwich panels for both sandwich systems. In Caprino's model, the rate of strength reduction is described by the exponent (0.450 for SC10 and 0.400 for SC20). With the parameter values for the Weibull distribution of the unimpacted structure and the strength reduction behavior of the impacted structures, it is possibe to predict the residual strength distribution under any incident impact

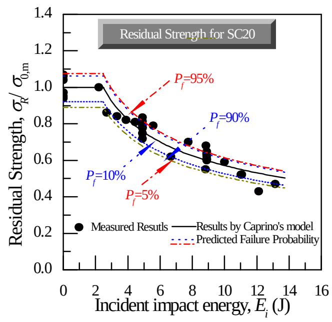


(a) SC10 (b) SC20

Fig. 1 Strength reduction behavior in impacted sandwich panels



(a) SC10



(b) SC20

Fig. 2 Distribution of residual strength in impacted sandwich panels

energy level. Theoretical prediction is plotted in Fig. 2 as a dotted lines (failure probability of 90% and 95%) and the experimental data as circles. The predicted results well describe the experimental results.

4. CONCLUSIONS

This paper provides a new approach to identify the statistical distribution of residual strength in impacted sandwich structure. The approach is relatively simple and derived from the Weibull distribution of strength in unimpacted structures and strength reduction behavior of impacted structures. By the experimental program for honeycomb core sandwich structures, the approach is capable of predicting the distribution of residual strength at any impact energy levels. Also, the scatter of residual strength in the sandwich structures decreases rapidly as the impact energy increases due to their impact damage.

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