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Damage tolerance and durability of selectively stitched stiffened composite structures

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Abstract

Through-the-thickness stitching is one of the promising approaches to improve the impact damage tolerance of stiffened composite structures. In this research, the effect of selective stitching on impact damage tolerance and fatigue durability of stiffened composite panels was extensively investigated and compared with unstitched stiffened composite panels. Two-blade stiffened composite panels were fabricated by resin film infiltration technique. Impact damage was inflicted on the stiffened panels using a drop-weight with the impact energy of 30 J from the skin-side over the stiffener and the flange. The experimental results indicate that selective stitching is an effective way to improve the compressive failure strength and fatigue strength of stiffened panels with both clearly visible flange damage (CVFD) and clearly visible stiffener damage (CVSD). The bulking and post-buckling finite element analyses were performed to predict the static compressive strength of the selectively stitched stiffened panels. A good agreement was obtained between analytical and experimental results. The failure behaviors of the undamaged, CVFD and CVSD panels were also investigated.

Keywords: Selective stitching; Stiffened composite panels; Impact damage tolerance; Finite element analysis

1. Introduction

Composite materials have been used in the aerospace industry over past thirty years. However, their utilization in the primary load-bearing applications has been impaired by their low damage tolerance, i.e., high sensitivity to the out of plane failures resulting from low interlaminar strength. Stitching through the thickness has been demonstrated as an effective approach to improve the delamination resistance [1–9]. To develop the knowledge base required for certification of stitched composite structures used in air transportation systems, the compression behavior and constant-amplitude fatigue behavior of both unstitched panel and fully stitched panel with two stiffeners was extensively investigated in our previous studies [10–14]. The results showed that the most benefit of stitching is manifested in the strength of barely visible flange damage panels as stitching prevents stiffener separation in impact and during compression loading. The stitching induces stiffener damage instead of stiffener separation when impact is inflicted on a stiffener. Although the fully stitched panels have a better delamination resistance, higher compression strength and more tolerance of fatigue than unstitched panels, the fully stitched panels are more costly due to excessive amount of time and labor involved in stitching. The aim of the present study is to systematically investigate the effect of selective stitching on impact damage tolerance and fatigue durability of stiffened composite panels.

2. Specimen preparation and experimental procedures

2.1. Materials

Hexcel type 282 AS4 (3k)/3501-6 carbon/epoxy was used for this study. Hexcel type 282 is a plain weave fabric

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that has the same number of warp and fill yarns, at 4.92 yarns/cm. The yarn consists of AS4-3k fiber tow. The AS4/3501-6 is a well-characterized composite and amenable to the resin film infiltration process.

The panels used in this study were designed to be a two-blade stiffened panel as shown in Fig. 1. Aside from its overall dimensions, the panel is characterized by skin and stiffen thicknesses, stiffener spacing and height, and flange width. The skin and one half of the stiffener constitute a flange. Both the length and width of the panel are 254 mm. The skin consists of 13 layers of fabric and the stiffener 12 plies. The lay-up sequences are as follows:

Skin: $[0/90, \pm45, 0/90, \pm45, 0/90, \pm45, 0/90, \pm45, 0/90, \pm45, 0/90, \pm45, 0/90]_T$
Stiffener: $[\pm45, 0/90, \pm45, 0/90, \pm45, 0/90]_S$
Flange: $[0/90, \pm45, 0/90, \pm45, 0/90, \pm45, 0/90, \pm45, 0/90, \pm45, 0/90, \pm45, 0/90, 0/90, \pm45, 0/90, \pm45, 0/90, \pm45]_T$

2.2. Manufacturing of stitched stiffened composite panels

The stitched stiffened panels were fabricated in the following steps: (1) lay-up and stitching of skin and stiffener, (2) preparation of resin film and (3) resin film infusion in an autoclave. Stitching was done on a JUKI 200 industrial sewing machine with a working platform capable of handling up to 500 mm × 700 mm × 25 mm preform. A 1600-denier Kevlar thread was used for stitching and a 400-denier Kevlar thread for the bobbin. The stitching speed was maintained at 18 cm/min to minimize damage to the fibers near the stitch. The flange and stiffener region was stitched with 2.48 stitches per cm^2 and 1.24 stitches per cm^2, respectively. The same Hercules AS4 carbon fiber tows were used fill the gap at the joint between the stiffener and the skin.

Prior to infusion, a film was prepared using 500 g of resin, which is slightly more than required for 50% fiber volume content to ensure complete saturation of the dry preform. The refrigerated solid resin was crushed into fine particle smaller than 5 mm in diameter. Then the particles were spread evenly onto a mold and heated to 60 °C inside an autoclave for 20 min to form a flat film approximately 5 mm thick. The stitched preform was placed into the mold containing the resin film, pressed down using a roller, and the inner mold pieces were put into place. The assembly was placed in an autoclave and cured using a cure cycle which was a slight modification of the manufacture's recommended cycle with the first isothermal dwell at 135 °C rather then the recommended 121 °C. The higher isothermal condition was necessary to ensure low resin viscosity for maximum penetration.

Nominal dimension of the manufactured panel were 546.1 mm × 304.8 mm × 42.3 mm. Each panel was cut into two specimens using a high-pressure abrasive water-jet system. Overall dimensions of each specimen were 254.0 mm × 254.0 mm with two 25.4 mm stiffeners.

2.3. Experimental procedures

Impact testing was performed according to the "SACMA Recommended Test Method for Compression After Impact Properties of Oriented Fiber-Resin Composites, SRM 2-88" [15–18]. Impact loading was applied using a drop weight on a Dynatup 8250 drop-weight impact-testing machine with a 4.3-kg indenter having a 12.7-mm diameter tup. Before impact testing the panel was held between top and bottom end plates with a groove. To this end, 350 g of Cerrobend® was melt in a ceramic cup at 100 °C for 15 min inside an oven. The top and bottom plates were placed inside the oven and the molten alloy was poured into the grooves in the heated plates. The plates were then removed from oven, placed on a Plexiglas support for better alignment, and the composite panel was slipped into the grooves. The entire panel assembly was then allowed to cool in the ambient temperature. The panel assembly was placed on the Dynatup base frame with the end plate

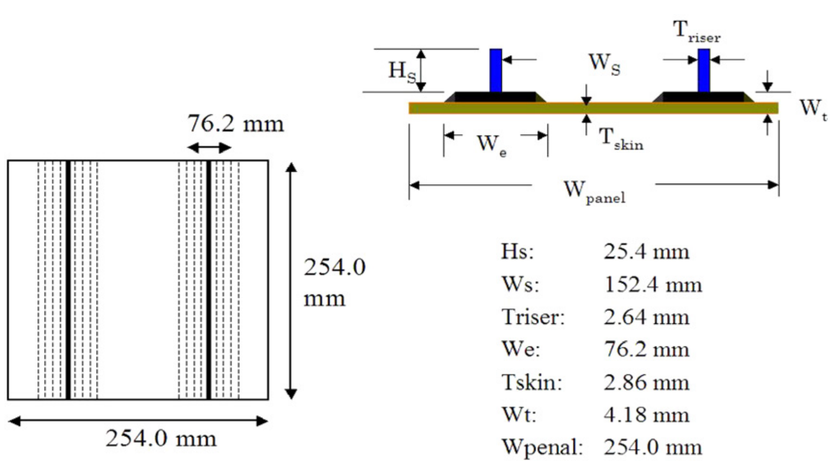

Fig. 1. The geometry and dimension of two-blade stitched stiffened panel.