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Experimental investigation of single and repeated impacts for repaired honeycomb sandwich structures

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ABSTRACT

Single and repeated impact behaviors of repaired honeycomb sandwich structures which are used in cargo panels at A319/A320/A321 Airbus were examined. Firstly honeycomb sandwich composites with detected impact damages which are in the limits of Aircraft Maintenance Manual and Repair Manual were repaired according to these manuals. Preliminary single low-velocity impact loadings were performed for original and repaired samples in order to find the energy limits which were ranged from fully elastic energy level to perforation energy level. At low-velocity single impact loadings, impact properties and damage mechanisms which occurred at both surface and internal parts of the materials were discussed from force- deflection (F-D) curves. In the second part, low-velocity repeated impact tests were performed with the determined impact energy levels. Repeatedly impact loading properties were also discussed with F-D curves. Impact damages which occurred in front and rear faces of composite structures were determined with digital camera. According to experimental results it was determined that impact behavior of repaired honeycomb composites is sufficient to be used in aircrafts.

1. Introduction

Composite materials were firstly used in military aircraft in the 1960s and then that extended to civil aircrafts at 1970s But, civil aircraft manufacturers were slower to utilize composites in primary structural parts until the 2000s. Now, as leading aircraft manufacturers replace conventional materials such as aluminum with advanced composite materials, the full potential of composites can be exploited through novel structural designs [1]. Honeycomb sandwich structures exhibit static properties such as high stiffness-to-weight ratio and high buckling loads which are of great importance in the aeronautics field. Nevertheless, the current applications on commercial airplanes remain mainly limited to secondary structures like control surface or floor panels [2]. Aircraft structures require regular inspections (with procedures established by the aircraft manufacturers and airworthiness authorities such as the Federal Aviation Administration and the European Aviation Safety Agency) to ensure structural integrity, efficiency and safety [3]. The continued airworthiness of aircraft composite structures depends on several factors (e.g. impact damage, delamination, debonding, manufacturing defects). During service, structural damage can initiate from manufacturing defects (e.g. voids, weak bonds) or occur due to mechanical loads (e.g. impact) and/or environmental exposure (e.g. moisture, temperature) [1]. Damage caused by impact loadings (e.g. dropped tools in service maintenance, cargo loadings and unloadings) can often be a critical threat to structural parts [4]. The impacts on composite structures are generally in the transverse direction (i.e. normal to the plane of the fibres), which in the absence of through-the-thickness reinforcement has relatively low damage resistance [1]. Therefore one of the main drawbacks for honeycomb structures is their poor resistance to impact [5,6]. In low-velocity impact, the dynamic structural response of the target is of utmost importance as the contact duration is long enough for the entire structure to respond to the impact and in consequence more energy is absorbed elastically [7]. Moreover, as the reduction in material strength depends on the type and size of damage; so accurate damage detection and quantification are essential for a robust aircraft structural maintenance and repair strategy [1]. Low-velocity impact usually results in internal damages such as debonding between face-sheet and core, face-sheet delamination and cracks in the face-sheet and core without any damage on the surface of the honeycomb structure [8–11]. Generally, nondestructive techniques are being used to determine location and extent of the damage. Once damage is detected and the

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effects on the residual properties of the structure have been estimated, a decision must be made as to whether this composite part should be repaired or replaced. If damage is not widespread and extensive, structural repair is the only feasible solution as replacing the entire component is not cost effective in many cases [12]. The main phenomenon of the composite repair is to restore the strength and stiffness of the impact damaged composite material and then to bring it nearly/original service condition back as much as possible [12]. Depending on the type and location of the damage, aircraft composite's repair can be injection, doubler or scarf based [13]. While resin injection repair is generally regarded as a temporary measure to stop the spreading of damage, doubler repair can provide a permanent restoration of structural strength, but not an aerodynamically smooth surface. Scarf repair can offer structural strength as well as a flush surface, and thus have greater potential for aircraft composite repair, especially for external skin panels [1]. At this point, there is not any study about the impact behavior of repeatedly impacted repaired honeycomb sandwich structures in literature. By this way, this study presents the effects of repeated low-velocity impacts on the impact fatigue life of repaired honeycomb sandwich structures. First of all, single low-velocity impact behavior of repaired honeycomb sandwich structures was determined by force-deflection (F-D) curves. After determination of low-velocity impact energy levels, main study was performed by applying the low-velocity repeated impacts on repaired honeycomb structures at the same impact energy level up to full penetration damage. F-D curves and impact surface/rear surface digital images were given and discussed for determining the impact life and damage mechanisms.

2. Material and method

2.1. Material

Gillfab 4422 is a honeycomb sandwich panel with facings of woven fiberglass reinforced phenolic laminate with 1 mil Tedlar® overlay bonded to Nomex® honeycomb core. The Gillfab 4422 is designed to use as cargo compartment lining in sidewalls, ceilings, partition walls and as decompression panels in the lower cargo hold in all Airbus Industry A300/A310/A300-600, A319/A320/A321, A330/A340 and A318 aircrafts (Fig. 1 and Table 1) [14]. The experimental samples in this study were prepared in 100 mm x 100 mm x 10.5 mm by cutting out from panel of 1219 mm x 3658 mm x 10.5 mm by using a water jet cut. Core and one of face thicknesses of honeycomb sandwich samples are 9.84 mm and 0.33 mm, respectively.

Beside this, for determining the impact behavior of repaired honeycomb sandwich structures, the square samples were deformed locally at the center. Repair process steps were given in Fig. 2.

Table 1
Properties of Gillfab 4422 honeycomb sandwich structure.

Thickness (mm)	10.5
Facing, Face/back (mm)	0.330/0.330
Length and width (mm)	1219×3658
Adhesive	Epoxy
Core	Nomex
Facings reinforcement	Fiberglass cloth

2.2. Drop weight impact test and surface damage evaluations

Low-velocity drop weight impact tests were performed according to ASTM D 7136 standard. Instron Dynatup 9250 HV impact test machine was used in impact tests which has an impactor with a total mass of 4.9716 kg and with a hemispherical diameter of 10 mm. The maximum falling height of the testing machine is 2 m. The drop-weight apparatus was equipped with a motorized lifting track. Data were stored in Impulse Data Acquisition Software after each impact and then the impactor was returned to its original starting energy level. Clamping system was designed to provide a uniform pressure all over the clamping area. Rebound catcher was adapted to the test device for catching the impactor on a stop during its second decent. For impact tests, square samples were fixed by clamping a rigid base with a 40 mm inner diameter to prevent slippage of the sample and impact tests performed. Impact energy levels which caused core crush, upper skin failure, rear skin failure and complete penetration were determined from F-D curves.

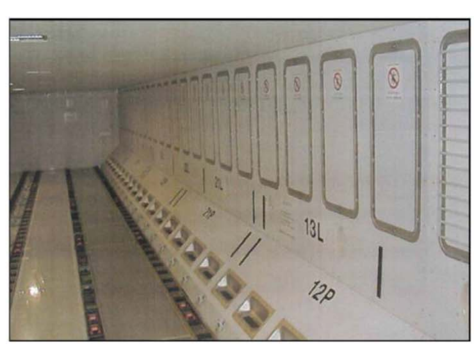
After repair process honeycomb sandwich structures were impacted under different impact energies up to fully penetration. Results of low-velocity single impacts were reported in terms of peak load and total deflection. Some researchers also used load-deflection histories to compare structural responses from low-velocity drop weight impact tests [15]. According to these results lower and upper repeating impact energy levels were determined. Repeated impact loading was performed with the energy levels between lower and upper values. After single and repeated low-velocity impact tests, impact damages which occurred at the front and rear surfaces of repaired honeycomb sandwich structures were examined by digital camera.

3. Results

3.1. Single impact loading results

In order to determine the impact behavior of repaired honeycomb sandwich structures, preliminary low-velocity impact tests were performed for original honeycomb sandwich structures. By this way, impact behaviors of original and repaired honeycomb sandwich structures can be compared with each other. Fig. 3 shows the F-D curves of original honeycomb sandwich structures under three impact energy levels (1 J, 3 J and 5 J).

-a-



-b-

Fig. 1. a-Gillfab 4422 panel, b-cargo compartment lining in sidewalls, ceilings, partition walls and as decompression panels in the lower cargo hold in Airbus A319/A320/A321.