SMART RESTORATION OF DEFECTS
IN DAMAGED COMPOSITE AERO-STRUCTURES

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Intensive Abstract

This research paper is in the area of structural healing technology with a focus on smart and sustainable composite repair techniques on aero-structures. It provides approaches to repair both barely visible damages (BVDs) which are internal, and visible surface defects of the laminate.

Current techniques to repair aircraft structure damages caused by bird strike, foreign object debris or any other sources are mainly concentrating on surface repair. It involves resin injection and patching externally. The current technology mainly considers the compression strength recovery, through evaluations with compression- after-impact (CAI) tests in ambient conditions. This leads to only restoring up to the 80% of the strength of materials, where only the surface layers are usually repaired. Internal damages as well as defects, which are barely visible, were often not addressed.
The current conventional procedure for aircraft repair involves the following procedures:

a) Pre-repair surface preparation are performed by removal of paints and materials at the damaged area by sanding, cleaning and vacuuming of dusts at the repair area which arises due to sanding.

b) Follow by repair treatment performed iteratively through resin injection and curing.

c) Patching with Prepreg laminates is carried out for an external repair, before soft sanding and painting for the final surface finishing.

However, mismatch of material properties between the repaired and undamaged parts caused inhomogeneity. In addition, such repairs have limited effectiveness, as it does not last for the lifetime of an aircraft, and the cost is expensive as aircraft will be unserviceable, due to long repair durations. The aim is to reduce the ‘waiting’ time of the aircraft in the hanger during repair.

Fibre Composites in the form of solid laminates were used in many industries, from aerospace, to automotive, marine, construction and renewable energy, where they requires repair for damaged composite. Common modes of failure found in all these applications are matrix cracking and delamination between plies. These failure modes affect the function of the material to take up load in compression and bending. In addition, the structural failure mode could be accelerated by fatigue and creep, and environmental factors, moisture inclusion into the damage region creates undue stresses due to phase change.

The aircraft industry is highly regulated, including the repair techniques. We have recently developed novel techniques to adapt into current repair strategy. Our techniques have been applied to Prepreg composite laminate of carbon/fibre epoxy of aerospace-grade and are representative of the materials in aerospace. These techniques involved portable vacuum-injection system and vacuum-bagging system, and a range of low-viscosity healants for prescribing practical and effective repair in different real-life situations involving barely visible damages. Key approach used in these techniques involve smart diagnosis by non-destructive testing (NDT) techniques, smart drilling of fine sub-critical-sized holes to permit access to this crack network, and healing of cracks networks through the use of a fusible or curable liquid phase to penetrate and fill up the micro-cracks and in some cases delaminated surfaces in the composite.
After BVD repair, the surface repair is applied on the aircraft to restore the surface back to its original condition to minimise any aerodynamic disturbances. The novelty in the surface repair includes an improved resin infusion technique, which uses a thin layer of low-viscous resin injected under a thick double-sealed bag with maximum vacuum to push the resin inside the external cracks and possibly in the remaining internal cracks, under a wide range of room temperature. This proposed procedure is completed with the standard aviation industry surface finishing procedures, where 3-layer of painting are performed. Overall, this internal and external repair technique is expected to enhance the structural strength and make the entire repair more efficient in terms of low equipment used, low cost for labour and repair, quick turnover time for aircraft to be serviceable, and ease the process for certification and approval to implement of repair techniques.

To quantify the healing effect and repair quality, the experimental work of this research mainly rely on established methods for incorporating reproducible damages into composites. This is followed by the healing treatment through the measurement of mechanical strengths such as the tensile strength, torsional strength, flexural strength, interlaminar fracture toughness and fatigue of the before or after repair. The repaired composite specimens are mainly in the size of 160 mm by 100 mm and are investigated in laboratory for different mechanical strength tests particularly compression after impact (CAI).

A repair technique is being developed for in situ repair of low velocity impact damage (LVID) in aircraft composite structures made from carbon fibre reinforced polymer (CFRP). In this technique, an in-house developed low-pressure resin-injection system is used to introduce healant into the cracks. The healant infiltration effectiveness depends on several factors, e.g. healant viscosity and the extent of the damage. A complementary technique involves creating vent holes to a specific depth around the damage site to expel air and debris out of the cracks in order to facilitate the healant infiltration. Unfortunately, further damage to the composite may occur during the drilling process; the presence of vent holes may affect the mechanical behaviour of the composite.

To this end, a preliminary study was conducted to investigate the effects of vent holes on the mechanical properties of CFRP laminates. Laminate specimens were subjected to quasi-static indentation to generate LVID-like damages. Ultrasound c-scan was used to map the damaged site. Compression-after-impact tests were conducted to quantify the
compressive stiffness, fracture strength and toughness of the damaged composites. No significant differences were found in the mechanical properties between the controls and damaged specimens with vent holes. Further study is underway to evaluate the mechanical properties of the LVID-like composites, following healant infiltration, as well as to compare the results with other known repair methodologies.

A resin injection system with flexible vacuum chamber (FVC) and the low-viscous resin infusion system are used for the repair of damaged Prepreg composite specimens. The study of damages and repair have been conducted using 2 NDT systems: Infrared Thermography (IR-T) and Ultrasonic C-scan Testing (UT). The compressive forces and stress-strain curves on different test specimens have been compared in the resin injection method by using Vacuum Bagging (VB) and by using FVC. The compression-after impact (CAI) tests have been conducted on pristine, damaged and repaired Prepreg composite specimens in the size of 160 mm by 100 mm.

The research team is aiming to provide a step-change in highly regulated aircraft repair technology, in keeping with the rapidly accelerating usage of composites in aircraft and in line with Singapore long-term planning and business strategy to gain number-one status as aircraft maintenance hub in Asia.

**Keywords:** Defect, Composite Repair, Aircraft Structure, Healing, resin Injection.