PATCHBOND II

EDA CAT B project No B.PRJ.RT.670

1 Introduction

PATCHBOND II was a European Defence Agency (EDA) Cat B project, No B.PRJ.RT.670. The project was a follow up of the project PATCHBOND. Within the PATCHBOND project, the bonded repair was studied for structural CFRP repairs as a complete process including certification requirements, analysis and design methodology, manufacturing processes/methods and in-service inspection/monitoring. The target was to enable repairs outside the existing structural repair manual limits. The certification approach selected in PATCHBOND project was based on Bonded Repair Coupons (BRCs) [1] for initial bond-line strength substantiation, and Structural Health Monitoring (SHM) systems for in-service monitoring of unexpected damages to the repair patch. The results of the PATCHBOND project were used as first steps towards certification of adhesively bonded repairs of primary composite structures aimed at overcoming the Bonding Repair Size Limit (BRSL). In this follow up project, PATCHBOND II, the work was continued, concentrating on improved repair processes and repair strategies to enable beyond BRSL CFRP repairs, as well as the integration of SHM techniques to monitor the repaired area. The key element in overcoming current repair size limits and to ensure the damage tolerance of damaged structures for bonded repairs is to understand the damage propagation in composite structures and especially in the bond-line.

Therefore, the objective of this project was to set the guidelines and analysis of bonded repairs to ensure the damage tolerant design philosophy. This included an initial assessment of the criticality of a damaged composite structure and a no growth/slow growth design approach in view of certifiable large composite repairs with larger bonded repair size limit than allowed by current certification policy.

The project was spit up in 5 work packages:

- WP 100: Management
- WP 200: Materials & Processes
- WP 300: Design & Analysis
- WP 400: Tests
- WP 500: Structural heath monitoring

An important issue with bonded repairs is the certification. Limit load capacity of a bonded repair must be proven by one of the following briefly summarized methods: design features to prevent critical disbond growth, limit load testing of the structure or repeatable and reliable inspection of the bonded structure. Within the work packages of PATCHBOND II, different methods are investigated for bonded repairs to comply with those rules.

Within WP 200 repair processes were investigated for fast temporary repairs, bonded repair coupons for certification of processes or inspections and the effect of ageing on repairs materials.

Within WP 300 the focus of the investigation was on the no growth of slow growth properties of repairs. Is the crack growth rate predictable using analysis methods and if so, can crack stoppers be designed and used to stop growth?

A large number of tests were accomplished in WP 400 to demonstrate the designed methods and philosophies of WP 300 and 500.

Within WP 500, the use of structural health monitoring was investigated to monitor the behaviour of repairs during the remaining life of an aircraft.

2 Work package 100: Management

The following partners were part of this project:

- Lead contractor: Royal Netherlands Aerospace Centre, NLR, the Netherlands
- Tampere University Foundation sr, TAU, Finland
- Patria, Finland
- VTT Technical Research Centre of Finland
- Wehrwissenschaftliches Institut für Werk- und Betriebsstoffe, WIWeB, Germany
- Airbus Defence and Space GmbH, Airbus DS, Germany
- University STUTTGART, USTUTT, Germany
- KVE Composites Repair B.V.,KVE, the Netherlands
- Fokker Services, Fokker, the Netherlands
- Norwegian Defence Research Establishment, FFI, Norway
- Norwegian Defence Materiel Agency, NDMA, Norway
- FiReCo, Norway
- Light Structures, Norway
- Politecnico di Milano, POLIMI, Italy
- Czech Aerospace Research Centre (VZLU), Czech Republic

A Project Arrangement Management Group (PAMG) was formed to monitor the project and approve the milestones and deliverables. The PAMG consisted mainly of MoD representatives of the contributing Member States and chaired by the Dutch representative. The following MS formed the PAMG: Czech Republic, The Netherlands, Belgium, Norway, Finland, Italy and Germany

The original project was started at 25 June of 2020 and was planned to continue for 4 years until 24 June 2024. Due to some small delays in the test activities, an amendment was issued with a new end date of 24 June 2025.

3 Work package 200: Materials & Processes

Within PATCHBOND mainly wet lay-up repairs were investigated. PATCHBOND II concentrated on prepregs materials for the repair. In WP 200, the materials were selected to be used in this project. Most of the materials selected were based on the materials of the NH90 helicopter and on standard repair prepregs. Standard repair prepregs minimize the number of stock material in repair work shops. Processes were studied for the preparation of the repair area, including pre-treatments and inspection methods. Different repair methods, like secondary bonding were compared with pre-manufactured repair patches for quick in field repairs. The use of bonded repair coupons was investigated for mechanical inspection of the bonding. The effect of ageing on bonded repairs was investigated to see if bond layers react similar to humidity as the original materials.

4 Work package 300: Design & Analysis

Within work package 300 of this project, the focus was on the analyses of damages in bonded repairs. The damages were characterized for two damage scenarios: bond-line defect(s) and barely visible impact damages (BVID). In this work package, analysis methods are evaluated and further developed to predict crack propagation in a static and fatigue loaded bonded repair joint. The analyses were performed from micro level, through meso level, and up to macro level for simulation of damage initialization and propagation process. The disbonds and crack propagations were compared with the test results of WP 400. Crack arresting methods/features like rivets/bolts were added to the bond-line. Also, different scarfing ratios were investigated which gave different crack growth behaviour. For the analyses different FEM methods were used.

5 Work package 400: Tests

Within WP 400 of PATCHBOND II, coupons (or specimens) were made to support work packages 300 and 500. The major part of this work package was testing of different specimens. Tests were done on small coupons with or without structural health monitoring systems mounted. With the results, new tests were specified in the work packages. Static and fatigue tests were performed on element level with specimens with different overlap lengths. Also, a large number of panel tests were performed to support WP 300. Panels of 500 mm width with different scarfing ratios were tested with impact damages and crack stopping features. Crack growth measurements were done using ultrasound and optical fibres. Finally biaxial panels will be tested to investigate the crack stopper mechanisms.

6 Work package 500: Structural heath monitoring

WP500 of PATCHBOND II focuses on the use of structural health monitoring (SHM) systems to support the monitoring and overall maintenance of the composite repairs considered in the other WPs of the project. The work of this WP (as do the other WPs) has considered different material systems, have done model analysis to support the repair and monitoring, as well as done testing – on coupon and test panel/component level in laboratories. In-flight testing on board a Dutch NH90 helicopter is also planned, but this has not yet been conducted.

WP500 has consider different SHM systems and how to integrate and utilize such systems to meet the certification requirements for a bolt free primary structure composite repair. A first bonded repair certification strategy approach for SHM was developed as part of the project PATCHBOND – "Bolt free battle and operational damage repairs of metal and composite primary aircraft structures" (EDA B-2324-GEM1-GP; 2014-2019). The PATCHBOND certification approach used SHM for detection of an unsystematic problem of the bonding process (local disbond) leading to a damage growth and the detection of discrete source damages that may occur during operation or maintenance. Damage categories relevant for SHM for monitoring of a composite bonded repair were defined. As an example, a local (slowly) growing disbond may not directly be visible to the aircraft crew during walk around inspection, but limit load capability of the composite bonded repair may be affected (requiring immediate repair after recognition).

To utilise an SHM system for composite bonded repair monitoring, the system has to demonstrate the capability to detect (and also evaluate) defects before the defect size becomes critical. To prove the damage detection capabilities of an SHM system, a method/procedure that helps the decision makers in their analysis and evaluation, has to be developed to accurately identify the probability of detection (POD) for prediction of the performance of the SHM system, utilized for composite repair integrity monitoring.

WP500 has been organized in five work elements (WEs), covering the definition of relevant damage scenarios, relevant SHM systems, certification requirements and available standards and procedures for the certification (WE510), design of an SHM system for a given damage case for implementation on an NH90 (WE520), numerical models and simulation tool development for prediction of damage growth (WE530), laboratory tests on coupon and test panel/component level (WE540), and in-flight testing on a Dutch NH90 (WE550).

7 General conclusions

The objective of this project was to set the guidelines and analysis of bonded repairs to ensure the damage tolerant design philosophy for larger repairs beyond the standard Bonding Repair Size Limit (BRSL) in a repair manual. The certification of a damage tolerant bonded repair was investigated based on different principles.

To prove the strength of a repair (limit load capacity), repair methods, bonded repair coupons and aging of repairs were studied. Limit load of the complete repair cannot be proven with the coupons, but the BRC's can prove if a good bonding process is used. The BRC's did not work as an inspection during the remaining lifetime, due to different aging behaviour of a BRC compared to the actual repair. Investigations about different surface pre-treatments, smart patches and surface inspections increased the knowledge about the repair processes.

Crack stoppers were investigated to certify a repair, based on design features to prevent critical disbond growth. Several tests were done on large panels with straight scarfs to prove the concept. Analyses methods were developed to prove the concept. The results are very promising, but need some adjustments to be used on a repair itself.

Structural health monitoring methods were investigated to measure a possible crack growth of bonded repairs. A fibre Bragg grating (FBG) based sensor system has been tested out for use in flight. The sensor system has been thoroughly tested in a laboratory environment; mechanical loads and environmental exposure. It is believed that it is safe to fly with the test system. Additional preparations are done to be able to conduct successful in-flight tests. Next steps will include the final preparations of and conducting the in-flight tests.

A large number of tests were done in the project to support the different concepts for repair certification.

Overall, the certification of bonded repairs is even after this project difficult and still has to be done on case-by-case basis. But the knowledge about the different possibilities has increased significantly with the work performed in theent PATCHBOND II project.