1 Publishable summary

PROJECT CONTEXT AND OBJECTIVES

Even though composite materials are already used in the manufacturing of structural components in aeronautics industry a consequent light-weight design of CRFP primary structures is limited due to a lack of adequate joining technologies. In principle, adhesive bonding is the optimum technique for joining CFRP light-weight structures, but difficulties in assessing the bond quality by non-destructive testing (NDT) limit its use for aircraft structural assembly. In consequence, certification by the regulation authorities is restrictive.

The implementation of reliable adhesive bonding processes by advanced quality assurance is expected to lead to an increased use of light-weight composite materials for highly integrated structures minimising rivet-based assembly. The expected weight savings for the fuselage airframe are up to 15 %. These weight savings have further effects on the size and weight of the engines. From the overall weight savings, significant reductions in fuel consumption and hence CO_2 emissions per passenger-kilometre are expected.

In ENCOMB, a multidisciplinary consortium of 14 partners from nine European countries brings together leading experts from top-level European research organisations, universities, and industries active in aeronautics research and development. The participation of three major European aircraft manufacturers ensures the compliance with relevant application scenarios, technological specifications and thus the use of the full exploitation potential of the results.

In order to ensure the performance of adhesively joined load-critical CFRP structures, technologies suitable to detect adhesion properties of bonded components and to monitor the physico-chemical properties of adherends and adhesives are required. As conventional NDT methods are focused on the detection of material defects like debonding, delamination, cracks etc., they are not suitable for these purposes. Therefore, a novel class of non-destructive testing techniques, classified as Extended NDT (ENDT), are required. The principle of ENDT methods is based on the detection of selected physico-chemical properties which are important for the performance of an adhesive bond.

The main objective of ENCOMB is therefore the identification, development, adaptation, and validation of ENDT methods for characterisation of adherend surfaces and adhesive bond quality. To this aim, the following aspects will be addressed:

- The study of promising technologies with high and low technology readiness levels from the field of analytical and spectroscopic polymer and surface characterisation such as nuclear magnetic resonance spectroscopy, dielectric spectroscopy, infrared spectroscopy, terahertz spectroscopy etc.
- Demonstration of the potential to be suitable for measurements in the field of manufacturing, rework, and (in-service) repair for technologies with low technology readiness level (semi-automated operation, high reproducibility, adequate speed of measurement).
- Extensive evaluation of the testing methods regarding application scenarios that are important for adhesive bonding of primary structures in aeronautics industry, such as the effect of adherend surface contamination, of thermal degradation, and of the curing state of adhesives on adhesion properties and overall bond performance.

- The improvement of the detection capabilities and the sensitivity of the measuring techniques in order to assess the quality of adhesive bonds, adherend surfaces, and adhesives by quantifiable measuring results by the further development or adaption of the techniques.
- The determination of a variety of physico-chemical properties of adherend surfaces and adhesives by the application of ENDT.

WORK PERFORMED SINCE THE BEGINNING OF THE PROJECT AND THE MAIN RESULTS ACHIEVED SO FAR

ENCOMB is structured in four technical work packages: definition of application scenarios for adhesive bonding of composite structures along with technology requirements (WP1), preparation and contamination/degradation of test specimens (WP2), development of ENDT methods for characterisation of adhesives and adherend surfaces (WP3), and development of ENDT methods for adhesive bond characterisation (WP4).

Based on the identified seven application scenarios, specimens, test campaigns, and specifications for the development of the ENDT technologies were defined. For the technological development, a three-step test campaign has been established starting with a campaign to assess the suitability of each technology regarding the application scenarios; followed by two campaigns each targeting a subset of the scenarios for optimisation and verification of the detection capabilities.

Within WP2, two sample sets were prepared with regard to the application scenarios and requirements. To provide reference values for comparison of the ENDT results, all samples were characterised by laboratory analytical methods regarding their physico-chemical properties (e.g., by XPS, IR) and by conventional NDT methods regarding their structural integrity (e.g. ultrasonics, radiography). The mechanical performance of bonded samples was characterised by mechanical testing (GIC). The main result is a harmonised, reproducible, revision-safe supply of samples to all partners.

Within WP3, ENDT technologies for the characterisation of CFRP adherend surfaces were selected, adapted, and validated with regard to their potential to satisfy the application scenarios and requirements. Four different scenarios were investigated in the first test campaign: Hydraulic fluid/water and release agent contamination, moisture in adherends, and heat damage of adherends. In the ongoing second campaign, two of these scenarios (release agent, moisture) are being addressed to adapt and further optimise the technologies also with regard to the required level of sensitivity.

In summary, 19 ENDT technologies were tested. The results show that (i) the hydraulic fluid/water contamination is detectable by 9, (ii) release agent contamination by 4, (iii) moisture in CFRP adherends by 7, and (iv) heat damage of adherends by 5 technologies. Additional tests in the ongoing campaign will show whether the technologies can discriminate different levels of degradation. Five technologies will not be further investigated as they do not comply with the project requirements.

Within WP4, ENDT technologies for the characterisation of CFRP adhesive bonds were selected, adapted, and validated with regard to their potential to satisfy the application scenarios and requirements. Three different scenarios of weak bonds were investigated in the first test campaign: weak bond due to release agent or moisture contamination and poor curing of the adhesive. In the ongoing campaign the two weak bond scenarios are being investigated in detail and assessed by comparison to the reference characterisations.

In summary, 12 ENDT technologies were tested. The results show that (i) weak bond due to release agent is detectable by 4 technologies; (ii) weak bond due to moisture by 3; and (iii) poor curing of the adhesive by 1 technology. Additional tests in the ongoing campaign will show whether the techniques can discriminate different levels of degradation. One of the 12 technologies will not be employed in any further investigations of adhesive bonds as it is not suitable for that purpose.

A dissemination and exploitation plan was established and is continuously being updated and monitored according to the project progress. So far, 4 peer-reviewed articles were published and further activities are foreseen to promote the project results. The public website informs visitors about the aims and current progress (www.encomb.eu). For internal use a web-based resource-sharing, monitoring and communication tool has been set up.

EXPECTED FINAL RESULTS AND THEIR POTENTIAL IMPACT AND USE

In order to extend the use of adhesive bonding for load-critical CFRP primary aircraft structures quality assurance processes for ensuring the performance of the adhesive joints must be developed. ENCOMB targets this objective by identifying, screening, developing, and adapting NDT methods for the characterisation of CFRP bonded structures, the characterisation of the CFRP adherend surface state before bonding and the state of the cured and uncured adhesive.

The following results are envisioned to be realised by the end of the project:

- Analytical techniques for characterising adherend surfaces and adhesives and for the assessment of the quality of adhesive bonds.

  Though it is not mandatory to achieve a high technology readiness level within the frame of the project, the techniques will show the potential for application in the field of manufacturing, rework, and (in-service) repair.

- Knowledge about the effect of different contaminations on the adhesion properties and the overall bond performance according to the selected application scenarios.

  This includes the generation of a deeper understanding of the effect of contaminations on the adhesion properties and the overall bond performance. This will finally result in the availability of correlations between properties and bond strength.

- Algorithm(s) that will provide bonding guidelines.

  This result has to be seen in the context of the production of highly integrated structures with optimum combination of advanced composite materials. Using the obtained knowledge about the effect of contaminations on the adhesion properties and the overall bond performance, the novel bonding guidelines will consider parameters influencing the bond quality.

- Quality assurance concept(s) for adhesive bonding of primary structures in aircraft manufacturing and in-service environment.

  This result is directly connected to the first result outlined above. The novel analytical techniques in combination with the obtained knowledge about the effect of contaminations on the adhesion properties and the overall bond performance results in concepts how to ensure the bonding quality during manufacturing and in-service.

The impact of the technological and scientific innovations of ENCOMB will be on a technical side (i) novel light-weight design of CFRP structural components resulting from the obtained knowledge about assembly of highly integrated structures and (ii) decrease of human error during production, maintenance, and repair which directly results in more reliable processes and increased safety of air transportation. On a socio-economic level, the increased use of advanced light-weight composite materials will result in a reduction of fuel consumption which is directly connected to the operational cost of an aircraft leading to more affordable air transportation. Secondly, due to better processes and reduced operational cost, the competitiveness of the European aircraft industry is strengthened and thus employment secured or even increased. The lower fuel consumption has significant ecological benefits by reduced emission of CO_2 and other toxic gases. This will be an important contribution towards the greening of the European air transport. Outside the aeronautics industry, the development of robust and reliable adhesive bonding processes enables the reduction of scrap rates due to a decrease of reject. This reduces the waste pollution resulting in a more environmental friendly manufacturing.

For more information please visit our website at www.encomb.eu