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A hybrid bondline concept for bonded composite joints

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ABSTRACT

Based on the experience in the past and the occurrence of in-service damages, the authorities restrict today the application of adhesive bonding of composite structures for aircraft applications. However, certification limitations can be overcome if occurring disbonds within a bond are stopped by implemented design features, so-called disbond stopping features. Consequently, a novel bondline architecture for bonded composite joints is proposed. By implementing a distinct rather ductile thermoplastic phase, a physical barrier for growing disbonds is obtained and thus a fail-safe design, respectively. Moreover, the joint is established by using two different joining technologies, namely adhesive bonding and thermoset composite welding. A sophisticated manufacturing technique is developed for the hybrid bondline concept to achieve a high strength joint. The joint's quality is examined by means of several analytical methods like microsections, scanning electron microscopy (SEM), and energy-dispersive X-Ray (EDX) analysis. Additionally, the mechanical performance is evaluated by static Double Cantilever Beam (DCB) and Single Lap Shear (SLS) tests.

1. Introduction

1.1. *Today's usage and limitations of bonded composite joints*

Due to their superior weight to strength ratio, composite materials are increasingly used in aircraft primary structures. This tendency becomes evident with the composite usage for Boeing 787 and Airbus A350XWB exceeding 50%. The implementation of more CFRP load-bearing parts demands efficient solutions in terms of joining technology.

With bolting on the one hand and adhesive bonding on the other, there are two joining techniques available for thermoset composites which are the majority of composites used for aeronautical applications. From a mechanical perspective, adhesive bonding is the favorable joining technique for several reasons. Adhesive bonds lead to weight reduction, offer a more uniform load distribution, are capable of joining thin-walled parts and minimize material weakening. The presence of fasteners has a noticeable impact on the part design and could even be a key dimensioning factor. Thus, fasteners hamper the full lightweight potentials of composites [1]. Therefore, the development of adhesive bonds being capable for certification is of high interest.

For civil aircraft, bonding of composites is well-established for various secondary joints. Airbus A380 features bonded joints for instance in the rear pressure bulkhead, the ailerons, the vertical tail plane and the radome as illustrated in Fig. 1 [2]. For the latest aircraft of the Airbus family (Airbus A350XWB), a large share of stiffeners are (composite to composite) bonded joints leading to an overall bondline length of about 5 km per aircraft [3].

However, due to certification requirements (see Section 1.3) the implementation of bonded joints in aircraft composite structures is still limited to secondary joints or combined with so-called “chicken rivets” if used for primary joints. Those additional fasteners have to be capable to carry limit load in case of a global failure of the bondline [3]. Design benefits that come along with adhesive bonding do not come into effect, since fastening elements must be taken into account for part design. Thus, up to now the potential of adhesive bonding is not used to its full extent. The main reasons for this limitation are briefly discussed below.

1.2. *Reasons for certification limitations*

The manufacturing process of structural bonded joints is influenced by many factors, e.g. surface treatment, adhesive curing cycle, curing conditions (e.g. pressure and temperature distribution), entrapped adherend's humidity, and many more. Those factors may affect the long-term durability of the joint [4]. Judging their impact on the joint's performance is complex and still subject of current research

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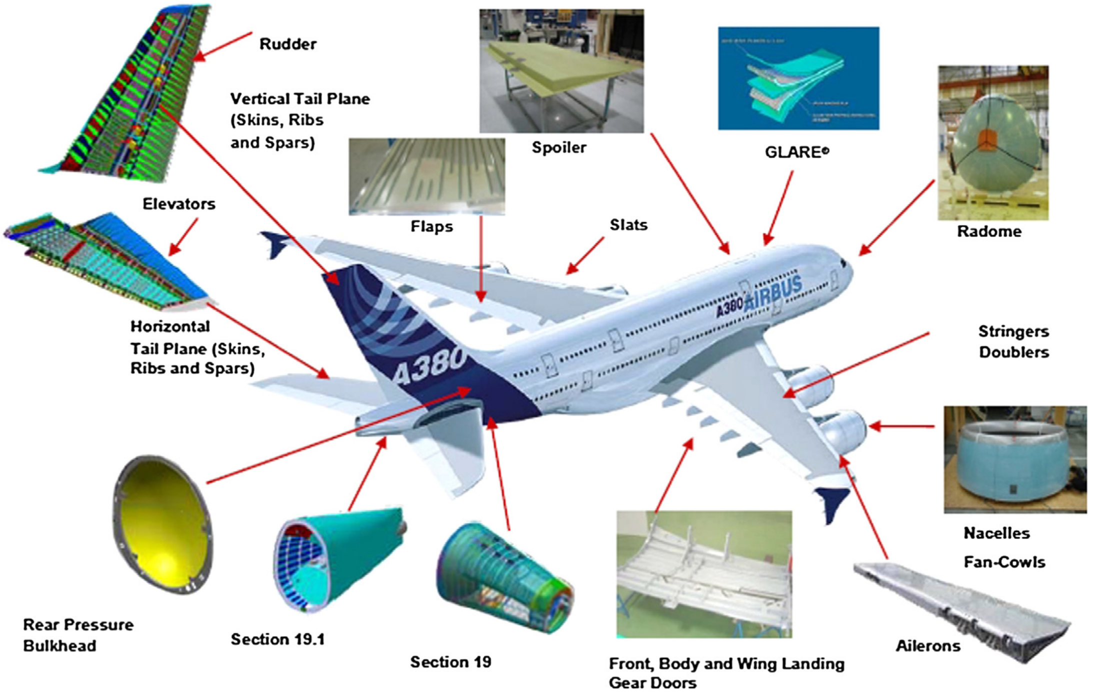

Fig. 1. Usage of adhesive bonding in the Airbus A380 [2].

and scientific discussions. Due to the absence of technologies for testing the quality of a bonded joint to full extent, a rigorous quality management system is required.

In addition to manufacturing uncertainties, aging and fatigue life of bonded composite joints is still challenging to predict and also influenced by many factors (e.g. load level, strain rate and environmental conditions) [5–8]. Thorough investigations of the interaction between those factors and their impact on the joint's long-term durability are hampered by the necessity of cost-consuming and time-consuming experimental fatigue studies. Furthermore, in-service damages (e.g. impact events) could hardly be avoided and may lead to a noticeable decrease of the joint's strength [5,9].

Eventually, all those factors led to a significant scatter in the performance of bonded composite joints in the past with some working well and some failing after short time in service [10]. Those experiences have caused distrust towards adhesive bonding as joining technology.

1.3. Certification requirements of bonded composite joints

Based on experience in the past and the uncertainties mentioned above, the authorities, namely the Federal Aviation Administration (FAA, USA) and the European Aviation Safety Agency (EASA, Europe), specify two major prerequisites that have to be met to achieve certification of bonded composite joints for primary structures [4,11].

The manufacturing process must be specified, controlled and monitored and has to be carried out in a pre-defined manufacturing process window regarding influencing parameters. Consequently, influencing parameters and their tolerable deviations have to be determined. Despite a rigorous manufacturing quality management, one of the following methods has to be established to attain certification [4,11]:

1. Disbonds greater than a pre-defined maximum must be prevented by design features. The allowed disbond maximum must be determined by analysis, test, or both.
2. Proof testing has to be executed for every production article to ensure that the joint can withstand the desired design loads.
3. The load-bearing capability of each joint must be determined by repeatable and reliable non-destructive inspection (NDI) methods.

Proof testing of each production specimen is not desirable in serial production of large composite structures since testing is very cost-intensive. An NDI method that sheds light on the strength of adhesive bonds is currently not available. Porosities or voids may be detected by established methods like ultrasonic scanning or thermography. However, giving evidence that proper adhesion is achieved is not possible today [12].

In the end, a promising approach is to establish disbond-stopping design features. Those must be developed and incorporated in each bond to prevent a possible disbond reaching a critical extent. This initial situation is the major motivation for the developments that are made in the European project BOPACS of the Seventh Framework Program (FP7).

Several crack-stopping approaches are under investigation within the project like the so-called rivetless nut plates [13], small diameter pins [14] or surface modifications [15]. Another promising approach is the hybrid bondline concept which is introduced here.

The denotation *disbond* and *crack* are used synonymously in this work to describe the joint's (local) separation within the bondline.

2. The hybrid bondline approach

2.1. Working principle

Many conventional epoxy adhesives for aeronautical applications are toughness-modified in order to reduce undesired brittle behavior that inherently applies for pure epoxy systems. For instance, rubber particles could be used as toughening material as proposed by Ranta et al. [16] and Kinloch et al. [17]. However, adhesive toughening by incorporation of rubber or thermoplastic particles may leads to a degradation of stiffness and strength. Therefore, toughening may be seen as a compromise between ductile behavior of good nature and