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# Static and cyclic strength properties of brittle adhesives with porosity

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ABSTRACT

Adhesive joints play an important role in structural reliability and durability of assembled load carrying structures. This research is inspired by the application to wind turbine blades, which are built up of composite materials and joined to each other with adhesives. In contrast to traditional guidelines for adhesive joints, wind turbine blade joints have high thickness, in the order of 10 mm. The probability of presence of voids and porosities is high. Still, the machine has an economical life of 20 years and fatigue may be a critical phenomenon. This research focuses on a bottom-up adhesive properties characterisation and its validation in composite joints, at successively levels. It starts from the characterisation of bulk adhesive going through bonded joint specimens and subcomponents. This paper focusses on the levels of the adhesive material itself and of the joint. After an extensive experimental campaign with particular attention to porosity in the adhesive a probabilistic approach is developed to identify the most appropriate failure criterion. The strength prediction method considers a statistical size effect in the strength of the material by considering not only the magnitude of the stress distributions, but also the volume over which they act. This approach is subsequently used for the numerical prediction of the strength of joints in simple joints and in an application which is inspired by a wind turbine blade. The predicted resistance of joints is in close agreement with experimental joint tests.

*Keywords:* brittle adhesive; wind turbine blade; experimental campaign; probabilistic approach.

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## 1. Introduction

Technology for adhesive bonding is available already for a long time and it is used in different applications and different sectors of industry. For some sectors specific guidelines have been developed over time and sometimes quite detailed procedures for design, testing and verification are defined. Guidelines and procedures tend to be different as design drivers and conditions of loading, utilisation and exploitation may be very different. Also different countries may have different specifications and procedures. Adhesive bonding and other load transfer details are major subjects in different research branches [1-5].

One of the early adopters of adhesive technology with a particular focus on reliability and fatigue was the aerospace industry, and specifically the US military, who established criteria already back in the late seventies of the 20$^{th}$ century. Tools used to design bonded joints were first validated as part of the USAF (US Air Force) Primary adhesively bonded structure technology (PABST) program [6]. The recommended design methodology (the aerospace design approach for bonded joints) is outlined in the US Composite Materials Handbook CMH-17-3G [7]. The computer code A4EI is widely used to assess the load bearing capacity of adhesively bonded joints and that this code was used for assessing bonded joints in F/A-18 (Hornet), F-15 (Eagle, and Strike Eagle) and Triton airframes. In addition to design methods, the USAF perform a risk analysis for operational aircraft [8]. This approach