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Probabilistic modeling of hybrid transition structures

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ABSTRACT

Within lightweight structures, often Fiber Reinforced Plastics (FRP) are used in combination with metallic materials. Most of these hybrid structures are manufactured by established methods like riveting, bolting or adhesive bonding. In order to avoid disadvantages like drilled FRP or large bond areas, the development of hybrid transition structures compatible to loads and material properties is required. To fulfill the requirements for enhanced lightweight design, novel, integral joint concepts are currently designed, dimensioned and produced by using textile, welding and casting techniques.

Three concepts are under investigation which consist of different materials (titanium and Ti-alloys, glass fibers), manufacturing methods (casting, welding, textile techniques) and geometries.

Various phase boundaries, materials and influences of the manufacturing processes have to be investigated that influence the structural behavior and its failure. Based on the results of Finite Element Models on the meso scale, further modeling is performed to include effects like material uncertainties and/or process influences.

In this paper, a probabilistic computation procedure based on local survival probabilities and distribution functions is proposed and investigated. This approach allows to model the complex global failure behavior for each component or its interfaces as well as the whole hybrid transition zone. It also shows the interactions and consequences of certain component changes within the hybrid transition zone. First computations are carried out and compared with experiments.

1. Introduction

A complete substitution of a material is not always purposeful for an effective use of the lightweight potential of a construction. The optimal overall structure consists of a hybrid combination of materials, the so-called multi-material design. The approach of local hybridization of structural components thus moves increasingly into the focus of the research interest [1].

To realize integral and thus lighter and slimmer designs, improved or new concepts and techniques are required [2], which are currently under investigation in the research group "Schwarz-Silber" (FOR1224) at the University of Bremen and the University of Applied Sciences Bremen supported by the German Research Foundation (DFG). A closer look into the overall motivation and the different approaches as well as the three investigated concepts, for example the foil concept (Fig. 1), is given in Refs. [3,4].

Within the foil concept, several materials and interfaces have to be considered that are responsible for the load bearing and fracture behavior. A closer look into the structure of the foil concept is given in Fig. 2.

The aim of the collaborative project of the Bremen Institute for Mechanical Engineering (bime) and the University of Applied Sciences Bremen is to adopt, develop and test failure models, which describe the failure behavior of the various connection zones.

The present work deals with the computational methods for the probabilistic description of the fracture behavior of the transition structure. Based on first modeling approaches with the foil concept (Fig. 2), a generalized approach is presented and compared to first experiments.

2. Modeling

In order to test the proposed probabilistic methodology, a simplified geometry is investigated experimentally and numerically, as depicted in Fig. 3. The investigated materials are Ti_6Al_4V and a CFRP prepreg based on an epoxy resin.

Compared with the standard approach for deriving survival probabilities in monolithic parts, where every volume element

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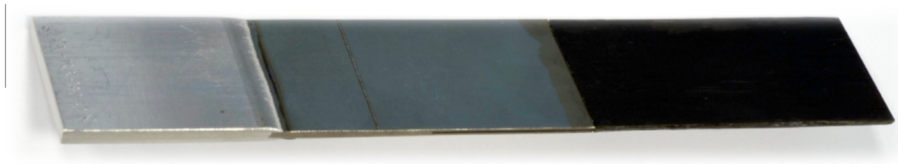

Fig. 1. Exemplary sample of the foil concept.

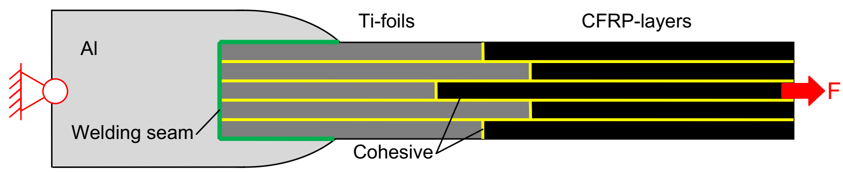

Fig. 2. Principle overview of the foil concept.

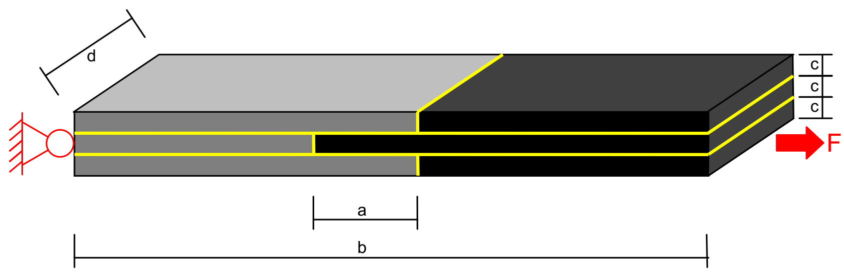

Fig. 3. Simplified testing geometry of the foil concept, with relevant dimensions: a. overlap, b. overall length, c. foil/laminate thickness, and d. width.

has the same impact on the global survival behavior, the investigated structure is heterogeneous. This implies that different parts have different influences on the global survival probability depending on local failure probabilities.

The investigation of complex systems regarding robustness or/and reliability is usually performed by Failure Mode and Effects Analysis (FMEA) or Failure Tree Analysis (FTA) [5]. Here, the extended systematic approach of the so called quantitative FTA not only allows to give quantitative results of the performance of the whole transition structure, but also to identify crucial parts of the structure.

First, the structure is transferred into a function diagram where every load bearing component is treated as a separate item. Connecting these items (Fig. 4), it becomes obvious that the system cannot be solved by rather simple serial or parallel coupling of probabilistic chains. The investigation of complex transition structures (like Fig. 2), consisting of several materials, layers and its interfaces, leads to quite complex mesh-shaped structures.

The FTA provides the tools to solve this kind of problems. By building load bearing paths called "Path Sets" and connecting them internally by Boolean "AND" (∧) operators (meaning chainlike behavior) and externally by Boolean "OR" (∨) operators (meaning separate load bearing paths), one obtains logic functions, like:

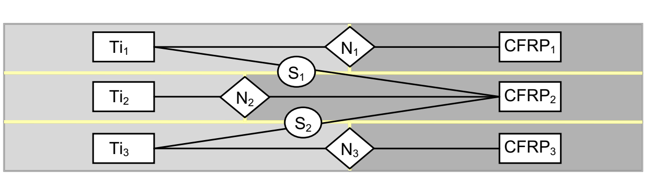

Fig. 4. Testing geometry interpreted in terms of FTA.

$$[Ti_1 \wedge N_1 \wedge CFRP_1] \vee [Ti_1 \wedge S_1 \wedge CFRP_2] \vee [Ti_2 \wedge N_2 \wedge CFRP_2] \vee [Ti_3 \wedge S_2 \wedge CFRP_2] \vee [Ti_3 \wedge N_2 \wedge CFRP_3] \quad (1)$$

By using of a few rather simple rules, where every "AND" produces a multiplication of the members and an "OR" resulting in more complex relations involving multiplication and subtraction of the form

$$\bigwedge_{i=1}^{n} x_i \Rightarrow \prod_{i=1}^{n} x_i, \qquad \bigvee_{i=1}^{n} x_i \Rightarrow 1 - \prod_{i=1}^{n}(1 - x_i) \quad (2)$$

the logical expression can be transferred into a semi mathematical form, where every P indicates a survival probability of the indicated item

$$1 - (1 - P(CFRP_1)P(N_1)P(Ti_1))(1 - P(CFRP_2)P(S_1)P(Ti_1)) \times (1 - P(CFRP_2)P(N_2)P(Ti_2))(1 - P(CFRP_2)P(S_2)P(Ti_3)) \times (1 - P(CFRP_3)P(N_3)P(Ti_3)). \quad (3)$$

By "semi mathematical form", it is emphasized that not all "common" calculation rules can be employed. In order to calculate the probabilities, the products have to be expanded according to the so called inclusion–exclusion principle, described in Ref. [6], where e.g. products of items or probabilities with itself are handled differently. In the end, one gets a complete mathematical form of the set, which can be handled without further restrictions to calculate a global probability, which has a quite similar appearance to conventional probability chains involving parallel and serial connections. Due to the length of the result of this operation, a strongly shortened version of the result is depicted (Eq. (4)).