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A NOVEL FINITE ELEMENT MODEL METHODOLOGY FOR THE GENERIC MODELLING OF ADHESIVE AGEING

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ABSTRACT

This work presents a novel approach of modelling adhesive ageing in a finite element context. Ageing phenomena affect the adhesive bulk material and adhesive-adherent interface differently. Both zones of an adhesive joint are thus to be modelled adequately to capture structural ageing effects. The adhesive bulk material is represented by a 3D mesh applying a nonlinear material model which allows element rupture. This is based on unidirectional tensile, compressive and shear curves. The adhesive-adherent interface is modelled by cohesive zone elements and seeded with mode I & II interface fracture toughness data. This approach allows for the simulation of cohesive, adhesive and mixed cohesive-adhesive failure of the adhesive bond. Through-thickness effects (e.g. due to moisture diffusion into the adhesive bulk material) are taken into account by dynamically updating the element material properties corresponding to the applied ageing conditions and duration.

Keywords: structural degradation modelling, adhesive ageing, adhesion, structural adhesive.

INTRODUCTION

Ageing processes of adhesive joints are very complex. There are many environmental factors which adversely affect the structural performance of adhesive bonds. For instance, temperature has a profound effect on the mechanical properties of the adhesive bulk material, changing the shape of the stress-strain curve (Fiedler *et al*., 2005); Moisture, in the form of bonded hydrogen atoms, also influences the adhesive-adherent interface region, leading to an irreversible reduction in adhesive strength and possibly adhesive failure (Sugiman *et al*., 2013). Degradation behavior is further complicated by the interaction between different environmental factors. Temperature not only influences the rate of moisture diffusion, it also affects the diffusion law (Datla *et al*., 2011).

Finite element modelling is being applied for many years to analyze the mechanical behavior of adhesive bonds. Recent research work concludes that adhesive bond, which are completely modelled with cohesive zone elements, yield results that agree well with experimental data (Banea *et al*., 2011). These cohesive zone elements express the failure behavior of the adhesive by means of a traction-separation law, which is defined using fracture toughness data obtained from physical testing. The cohesive zone approach has also been successfully used to investigate adhesive degradation (Fernandes *et al*., 2017). Although good results are obtained, the cohesive zone modelling approach lacks the ability to model both the mechanics of adhesive bulk material and adhesive-adherent interface separately, making it inadequate as a generalized model for adhesive ageing. Several tests are available to validate adhesive joint fracture models. They yield mode I, II & mixed-mode I-II fracture energy release rates and the most well-known is the Double Cantilever Beam (DCB) and End-Notched Flexure (ENF) test. An overview of the different methods is presented in (Chaves *et al*., 2014).

METHODOLOGY

In order to create a general and adequate adhesive joint ageing model which is applicable in a (commercial) finite element simulation context, a model is proposed that represents both the adhesive bulk material and the adhesive-adherent interface characteristics. The adhesive bulk material is modelled by a 3D hex mesh, while the adhesive-adherent interface is modelled using cohesive zone elements. Since the mechanical properties of adhesive material become (highly) nonlinear at elevated temperatures, a nonlinear material model is chosen to describe the stress-strain characteristics of the bulk material. This material model is based on unidirectional tensile, compressive and shear curves from aged adhesive bulk samples. Allowing the rupture of the 3D hex elements when reaching the end of the stress-strain curve enables the modelling of cohesive failure. A bilinear traction-separation curve is used for the cohesive zone elements (at the interface) based on mode I & II critical fracture energy release rates obtained from aged coupon samples. This traction-separation curve allows the modelling of adhesive-adherent interface damage, making it possible for the FE model to fail cohesively. To feed the FEM simulation with data from aged material, an extensive testing program is set up. The environmental influences considered in this work are the exposure to moisture and elevated temperature. Since the adhesive joint most often can be designed in such a way that the adhesive bulk material is shielded from UV, this ageing effect is not considered here. Therefore, the testing program will focus mainly on the degradation effects from the combination of moisture and temperature. Through-thickness effects (e.g. due to moisture diffusion into the adhesive bulk material) are taken into account by dynamically updating the element material properties in the solver input file based on ageing conditions and duration.

REFERENCES

[1] Banea M, da Silva L.F.M, Campilho R. Mode I fracture toughness of adhesively bonded joints as a function of temperature: Experimental and numerical study. International Journal of Adhesion and Adhesives, 2011, 31, pp. 273-279.

[2] Chaves F.J.P, da Silva L.F.M, de Moura M.F.S.F, Dillard D.A, Esteves V.H.C. Fracture Mechanics Tests in Adhesively Bonded Joints: A Literature Review. The Journal of Adhesion, 2014, 90, pp. 955-992.

[3] Datla N.V, Ulicny J, Carlson B, Papini M, Spelt J.K. Mixed-mode fatigue behavior of degraded toughened epoxy adhesive joints. International Journal of Adhesion and Adhesives, 2011, 31, pp. 88-96.

[4] Fernandes P, Viana G, Carbas R.J.C, Costa M, da Silva L.F.M, Banea M.D. The influence of water on the fracture envelope of an adhesive joint. Theoretical and Applied Fracture Mechanics, 2017, 89, pp. 1-15.

[5] Fiedler B, Hobbiebrunken T, Hojo M, Karl S. Influence of stress state and temperature on the strength of epoxy resins. 11th International Conference on Fracture, 2005, ICF11.

[6] Sugiman S, Crocombe A.D, Aschroft I.A. Experimental and numerical investigation of the static response of environmentally aged adhesively bonded joints. International Journal of Adhesion and Adhesives, 2013, 40, pp. 224-237.