Temperature dependent TAPO model for failure analysis of adhesively bonded joints due to temperature induced service loading

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1 Introduction

The Toughened Adhesive Polymer (TAPO) material model is available in LS-DYNA with the keyword **`*MAT_TOUGHENED_ADHESIVE_POLYER`** (**`*MAT_252`**) since the revision R7.1.1. It describes the mechanical behaviour of crash optimised high-strength adhesives under crash conditions by taking elasticity, viscoplasticity and damage due to plastic deformation into account—see [1,2]. Here, the model is implemented for a solid element into LS-DYNA and can be used for the cohesive elements (19) and (20) in **`*SECTION_SOLID`** with the option **`*MAT_ADD_COHESIVE`**. Also, the equations of the TAPO model are reduced to the interface theory in [2]. In this contribution, the reduced TAPO model in [2] is extended by temperature dependent viscoelasticity, plasticity and damage considering rate and temperature effects below and beyond the yield strength. Here, the focus of the material model is to predict failure of joints, which are bonded with ductile-modified adhesives and subjected to service loading with low strain rates due to temperature changes. The equations of the extended TAPO model are implemented into LS-DYNA as a "user defined cohesive model" for the eight node cohesive elements (19) and (20) in **`*SECTION_SOLID`** assuming a thin adhesive layer between the adherends [3]. Thus, the local interface traction $\mathbf{t}$ is described as a functional of the local separation vector $\mathbf{\Delta}$.

2 Thermo-viscoelastic-plastic model with damage

For the thermo-viscoelastic extension of the TAPO model, a generalised MAXWELL model and a thermal element are arranged in series—see Fig. 1. Thus, the separation $\mathbf{\Delta}$ is additively decomposed into a viscoelastic $\mathbf{\Delta}^{\mathrm{ve}}$, a plastic $\mathbf{\Delta}^{\mathrm{pl}}$, and a thermal part $\mathbf{\Delta}^{\mathrm{th}}$—see Fig. 1. The temperature dependency of the relaxation times $\hat{\tau}_i^{\mathrm{n,s}}$ of the MAXWELL chains is taken into account with the reduced time ξ, which depends on the shift function $a_{\mathrm{T}}(\theta(t))$ and the temperature $\theta(t)$ in the theory of thermorheologically simple materials. The relaxation functions in the convolution integral are DIRICHLET-PRONY series in normal and tangential direction:

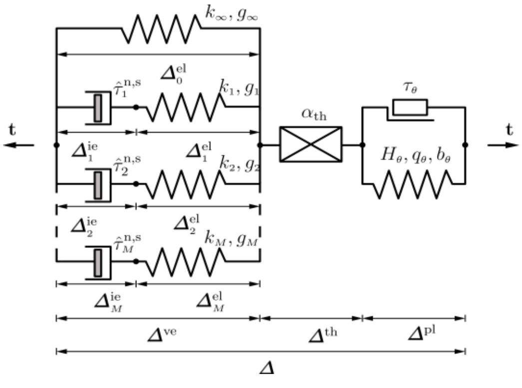


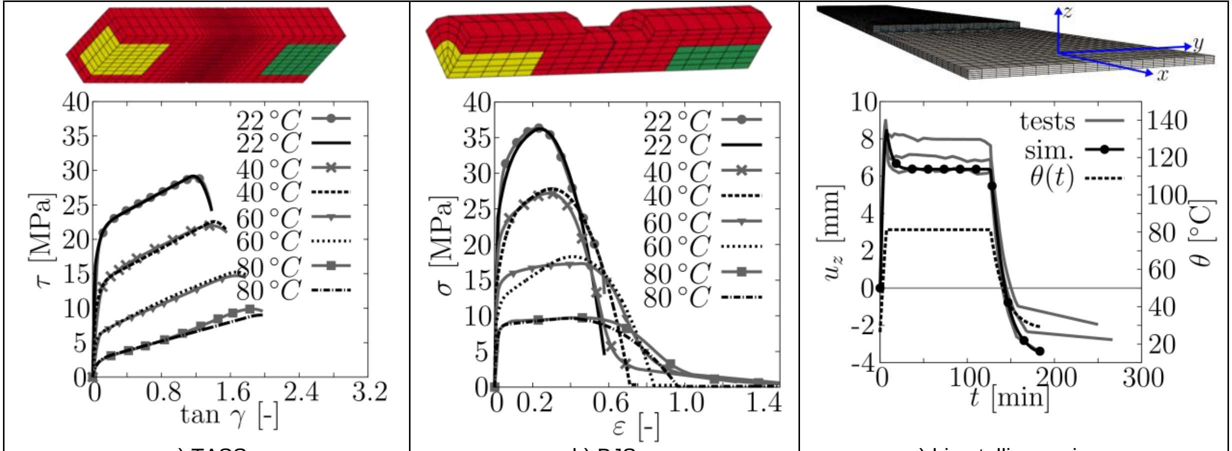
Fig.1: Rheological network of the model

$$\begin{pmatrix} t_{\mathrm{n}} \\ t_{\mathrm{t}} \\ t_{\mathrm{b}} \end{pmatrix} = \int_{-\infty}^{\xi(t)} \begin{bmatrix} R_{\mathrm{n}}(\theta_0,\, \xi(\mathrm{t})-\tau) & 0 & 0 \\ 0 & R_{\mathrm{s}}(\theta_0,\, \xi(\mathrm{t})-\tau) & 0 \\ 0 & 0 & R_{\mathrm{s}}(\theta_0,\, \xi(\mathrm{t})-\tau) \end{bmatrix} \frac{\mathrm{d}\left(\mathbf{\Delta}-\mathbf{\Delta}^{\mathrm{th}}-\mathbf{\Delta}^{\mathrm{pl}}\right)}{\mathrm{d}\tau}\,\mathrm{d}\tau \tag{1}$$

Furthermore, the yield stress τ_θ, the parameters of the nonlinear isotropic hardening stress H_θ, q_θ, b_θ, and the critical and failure strain in the damage approach of the TAPO model [1,2] are empirical functions of the temperature θ. The thermo-viscoelastic integral (1) is numerically integrated using a recursive algorithm and solved with the equations of plasticity by a predictor corrector scheme [3].

3 Parameter identification, model verification and validation

The parameters are inversely identified by fitting the model response to the related test data of the thick adherend shear specimen (TASS) and the butt joint specimen (BJS) by means of the optimisation program LS-OPT—see Fig. 2 a) and b). For the validation, a bimetallic specimen is tested, which consists of a steel and an aluminium sheet bonded with a ductile-modified structural adhesive. The test provides the deflection at the tip due to temperature loading, which is compared to the result of the related FE simulation. In the FE model, both sheets are spatially discretised by means of the enhanced solid element (-2) in `*SECTION_SOLID` and characterised by `*MAT_001` as well as `*MAT_ADD_THERMAL_EXPANSION`. The adhesive between the sheets is discretised using the cohesive element (19) in `*SECTION_SOLID` and is described by the extended TAPO model with `*MAT_USER_DEFINED_MATERIAL_MODELS`. For the FE simulation of the bimetallic specimen, the mean of the experimental temperature-time course is prescribed to the nodes using `*LOAD_THERMAL_LOAD_CURVE`. The deflection at the tip u_z of the FE simulation is compared to the test data in Fig. 2 c). As a result, the FE simulation is in good agreement with the measured test data.



a) TASS b) BJS c) bimetallic specimen

Fig.2: Comparison of test data (symbols) and FE simulation (dotted/dashed lines) of TASS a) and BJS b) with the identified material parameters. Validation of deflection at tip of the bimetallic specimen by means of FE simulation and test data c)—see [3,4]

4 Summary

The reduced TAPO model in [2] is extended with a thermo-viscoelastic model and functions of temperature for the isotropic hardening as well as for the ductile damage approach. Further, the implementation of the constitutive equations into LS-DYNA is verified with the test data of the TASS and the BJS and is validated with the bimetallic specimen for a temperature induced mechanical deformation.

5 Acknowledgements

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6 References

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