MULTISCALE ANALYSIS OF METAL / THERMOPLASTIC COMPOSITE INTERFACES

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ABSTRACT

The lack of maturity of composite crash simulation is still an issue in the introduction of composites in automotive mass production. This difficulty is amplified when one considers multi-material parts or assemblies. In the special case of laying thermoplastic composite tapes (using the ATL –Automatic Tape Laying - process) over a metallic surface, a key parameter is the texture of the metallic surface. The control of the texture involves the texturing process itself, the laying of the thermoplastic tapes and the mechanical performance of the final structure.
To this end, the present contribution deals with the numerical analysis of material interfaces between a metallic and a thermoplastic composite part. The goal is to develop an approach that allows for the simulation based characterization of laser structured material interfaces.

1 LASER STRUCTURED MATERIAL INTERFACES

The joinability of different materials is an key issue in the design of multi-material components. On the other hand the combination of certain materials in a single part allows for an significant optimization of lightweight structures towards performance and cost efficiency.
In the context of hybrid parts, consisting of metallic alloys and fiber reinforced polymers, the joint can be established utilizing the adhesive bond generated during the consolidation process of the composite. Since the generated adhesive strength is commonly significantly lower than the cohesive strength of the joint partners, the material interface is often the origin of component failure. An improvement of the adhesive properties can be achieved using chemical, electrical of mechanical mechanisms. The last mentioned category includes the generation of a mechanical interlock. On a microscopic scale this interlock can be generated through selective laser structuring of the metal surface (cf. Figure 1).

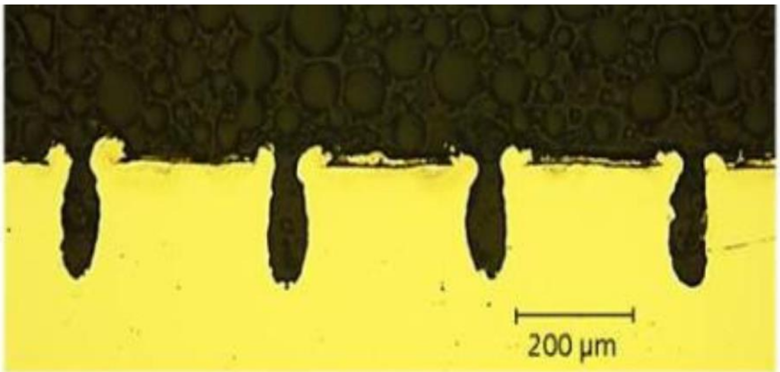

Figure 1: Micrograph of a laser structured composite-metal material interface.

2 MULTISCALE INTERFACE MODELLING

The evaluation of the performance of laser structured material interfaces usually requires extensive testing. In order to reduce the experimental effort, especially in an early design stage, a numerical modeling scheme has been developed. Following the works in [1,2], it is based on a multiscale analysis of the material interface that utilizes the contrast of length scale between the microscopic geometrical interface features and the macroscopic dimension of the hybrid structure. To this end, two scales are defined (cf. Figure 2). The characteristic length of the micro scale is of the magnitude as the size of the interface features generated by laser structuring, whereas the macro scale domain is of the same size as the hybrid part.

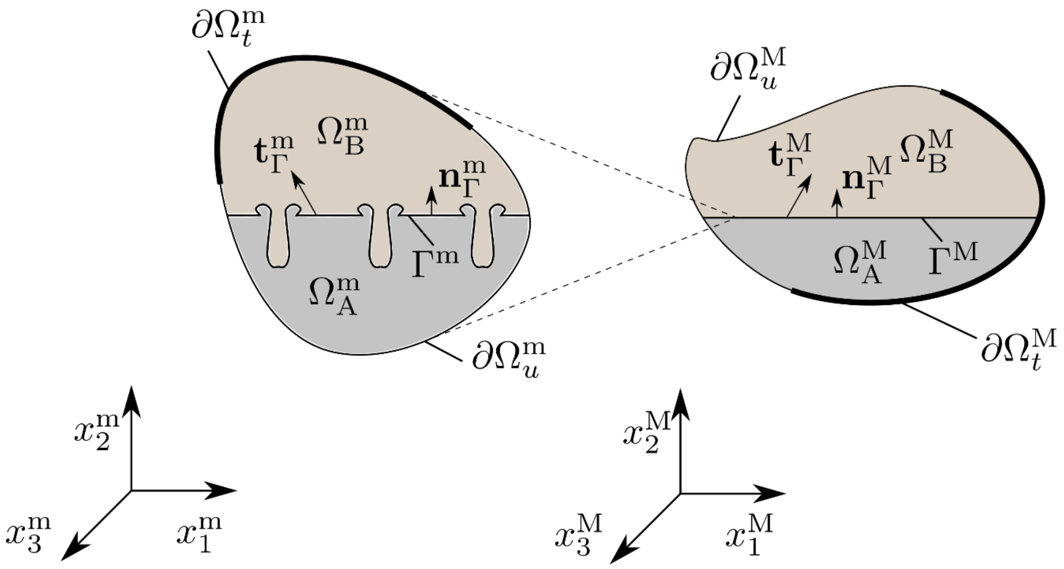

Figure 2: Micro-scale and Macro-scale domain definition.

The scale bridging between the micro- and the macro scale is accomplished using the well-known HILL averaging principle [3,4]. It relates the macroscopic virtual work density with the volume average of the total virtual work on the microscale.
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3 MODEL GENERATION

Depending on the complexity of the microscopic interface path, the model generation can become very cumbersome. To this end, an automated modelling scheme has been developed. Starting from a homogeneous mesh, elements that are intersected by the material interface are automatically identified (cf. Figure 3). An orthotropic material model with an internal cohesive damage approach is subsequently assigned to these elements.

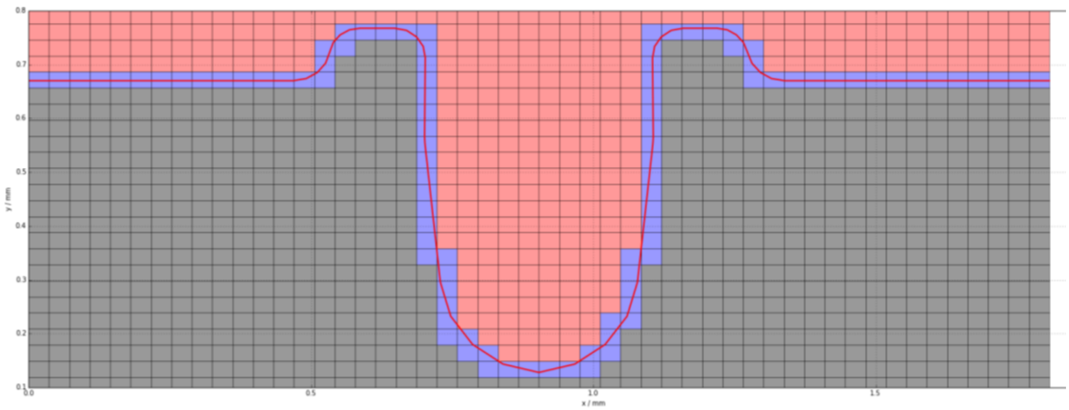

Figure 3: Micro-scale model generation with interface element identification.

3 CONSITUTIVE RELATIONS

The proper numerical modelling of the microscopic material interface substantially relies on the description of the microscopic damage phenomena. To this end, constitutive relations have been formulated for the individual material phases and the actual material interface. The latter is based on a cohesive damage theory that is embedded in a standard continuum material model [5]. The approach not only allows for an efficient model generation, it also reduces the mesh dependence of the derived results.

4 SIMULATION

The developed multi-scale modelling framework for laser structured material interfaces is subsequently applied to a set of evaluation problems. This includes the systematic analysis of the microscopic damage evolution for an idealized interface structure as well as for realistic geometries extracted from interface micrographs.

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REFERENCES

[1] M. Cid Alfaro, A. Suiker, C. Verhoosel, R. de Borst, 2010. Numerical homogenization of cracking processes in thin fibre-epoxy layers. In: European Journal of Mechanics - A/Solids 29 (2), pp. 119–131.

[2] F. Hirsch, M. Kästner, 2016. Microscale simulation of adhesive and cohesive failure in rough interfaces, In: Engineering Fracture Mechanics - accepted.

[3] R. Hill, 1963. Elastic Properties of Reinforced Solids: Some Theoretical Principles. In: J.Mech. Phys. Solids 11, pp. 357–372.

[4] R. Hill, 1972. On constitutive macro-variables for heterogeneous solids at finite strain. In: Proc. R. Soc. Lond. A., pp. 131–147.

[5] E. J. Pineda, A. M. Waas, 2013. Numerical implementation of a multiple-ISV thermodynamically-based work potential theory for modeling progressive damage and failure in fiber-reinforced laminates. In: International Journal of Fracture, pp. 93-122.