STRENGTH AND FATIGUE ANALYSIS OF ASSEMBLED COMPONENTS IN SMC COMPOSITE USING PRINCIPAL STRAIN HISTORY

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ABSTRACT

In the present paper a methodology to analyse strength and fatigue in SMC composite structures is described. The methodology is based on threshold strain levels for crack initiation and a damage mechanics approach is applied to estimate the damage level. Separate criteria are used depending on if the material is loaded in tension or compression. The material is considered in-plane isotropic but still the methodology is a useful tool. In particular, for a dynamic load case such as a door slam, the peak strain level experienced by the component is found and compared with the damage initiation level. For comparison of designs, the damage level of damaged elements in a FE-model is visualised.

1. INTRODUCTION

For SMC composites average stress, i.e. von Mises stress, is not a very good strength criteria mainly because the material's strength in compression and tension differs and the material is often anisotropic due to process induced fibre orientation. The SMC material is viscoelastic damageable but for short loading times, damage initiation and evolution is the important engineering parameter. SMC material has a threshold strain level for damage initiation [1,2]. The damage initiation strain is much lower in tension than in compression. The compressive strength is about twice the strength in tension. The damage is due to initiation and evolution of micro cracks. The damage evolution is in a thermodynamic approach governed by associated thermodynamic forces [3,4]. A fully non-linear material model has been developed [4], but for engineering use a more simple methodology is of interest in many cases. In this paper a methodology based on analysis of strain history is shown. SMC composite structures usually can be modelled with shell elements meaning a 2D strain state is analysed. The first principal strain is checked for crack initiation due to tension and the second principal is checked for crack initiation due to compression. The highest calculated damage is reported for the element. Both sides of the shell are analysed. For multiple loading cycles or loading under long time one must include time if calculating the damage level correctly. However a simplified approach applicable for large number of cycles and visible areas is to define that crack initiation is not allowed in certain areas. It is shown how the methodology can be applied to a dynamic load case, more specific a SMC door slam case.

2. TECHNICAL APPROACH

The technical approach applied is to make a simulation with a linear material model representing an in-plane isotropic material. Resulting strain from the load case applied is stored. The strain is converted to principal strain which can be compared with the threshold values obtained in uniaxial testing. Test data in tension has been obtained previously, see [3], and the damage initiation strain in tension is 0.25%. Damage development is considered using E-modulus decline:

$$D_i = 1 - \sqrt{\frac{\tilde{E}_i}{E_0}} \qquad (1)$$

Where $\tilde{E}_i$ is the damaged composite's Young's modulus and E_0 is the undamaged composite's Young's modulus. Using damage mechanics theory the damage evolution is governed by associated thermodynamic forces, which are a function of stress, stiffness and damage. In a non-linear formulation the damage has to be obtained in an iterative manner. In a simplified way applied here, the damage is estimated by using a strain-damage curve obtained in uniaxial tension and comparing with principal strain. To adjust the strain levels calculated with a linear material model, Neuber correction can be done, see Fisk [5]. Material data for damage evolution in compression has not been obtained, but based on strength differences in tension and compression, see for example [1], the damage evolution in compression is estimated to be half that of the damage evolution in tension per strain unit. The threshold strain in compression is estimated to 0.5%.

Comparison of designs is made based on the damage level, see figure 1. In low cycle fatigue, a static load case or when analysing fatigue in areas where cracks are allowed if the structural stiffness is still acceptable, it is also possible to state an acceptable damage level to have as design criteria.

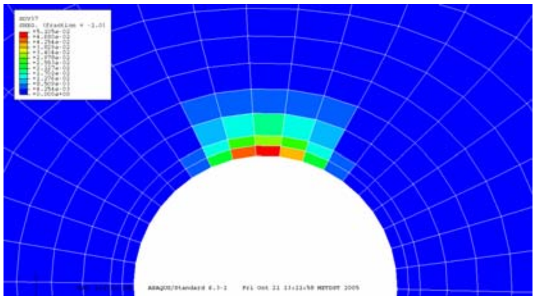

Figure 1: plot showing area around hole where strains above threshold level are visualised based on damage level. From Fisk [5].

3. MATERIAL DATA

The material data needed is the threshold strain for damage initiation in uniaxial tension and compression and the damage evolution Vs strain curve. The basis for this is the stress strain curve. For obtaining the damage-strain curve from the stress-strain curve, see for example [3]. For a SMC material this has been obtained previously [3], see figure 2 for the stress-strain curve and the figure 3 for the damage-strain curve in tension.

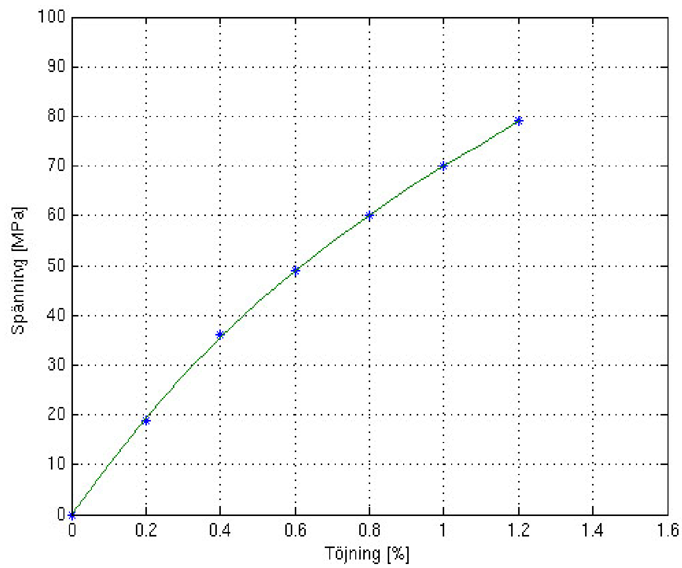

Figure 2: Stress-strain curve for a SMC material

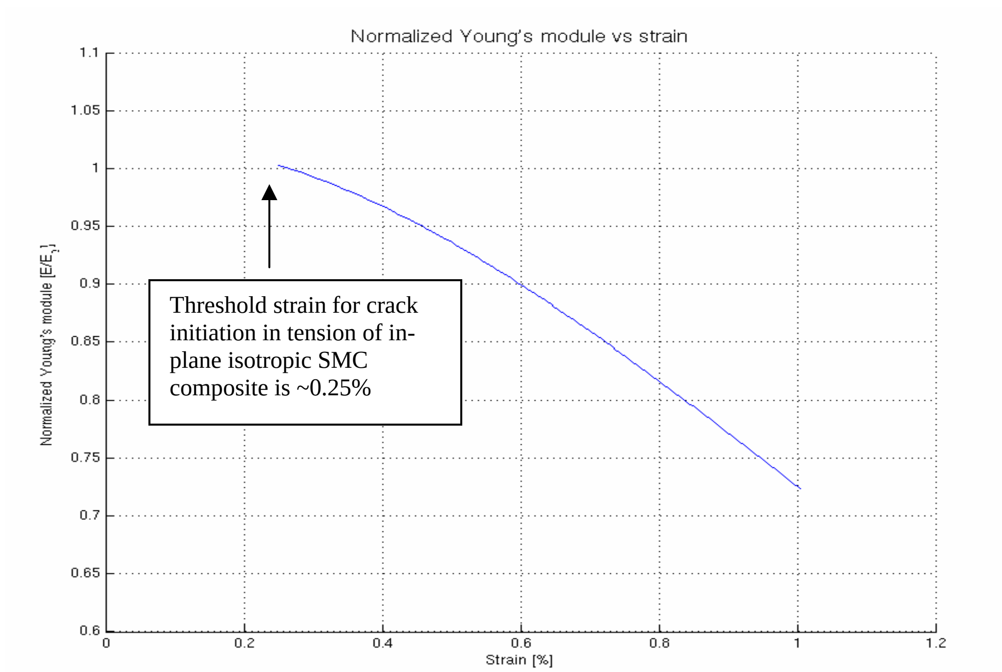

Figure 3: Damage –strain curve for a SMC material in tension.

4. APPLICATION TO DOOR SLAM

A dynamic load case needs a dynamic FE-analysis. Lately a non-linear transient methodology has been developed at Volvo Cars to fully simulate the load distribution in the door during a slam cycle and take in to account the non-linear seal, latch and bump stops.

Because the door slam simulation includes multiple time steps it is necessary to first make a sorting of the strain data to find the most critical time step in each integration point. After doing that the crack initiation can be evaluated in the same way as for a static load case by comparing principal strains with the strain Vs damage data. One criteria used is no crack initiation allowed in visible surfaces. This means the complete component is checked in a single slam cycle.

Polymers are sensitive to strain rate due to their viscoelasticity. To check for importance of strain rate in the door slam load case, maximum strain rate was analysed in a door slam and found to be less than 0.1, see figure 4. Research by Jendli et al [2] show that below strain rate 1, influence on threshold value for crack initiation in SMC is low, meaning the load case can be treated as static considering the crack initiation threshold strain.

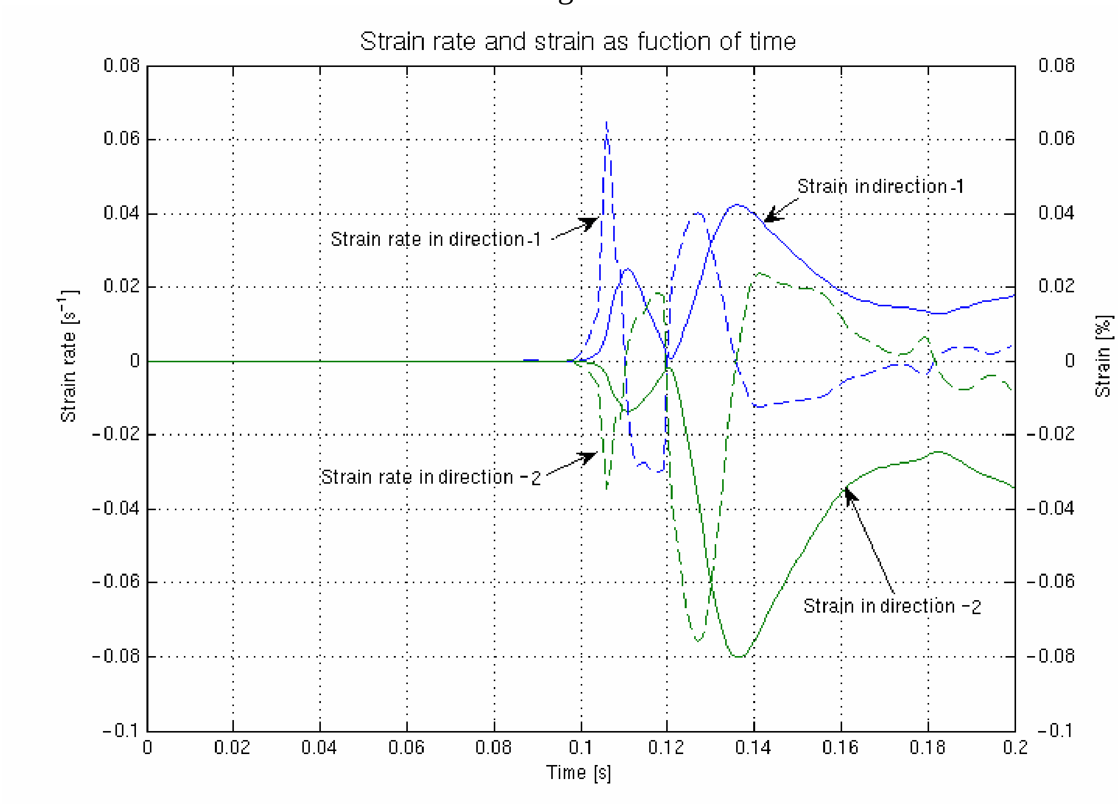

Figure 4: Strain rate Vs time in a highly loaded element during door slam

5. CONCLUSIONS

A methodology for strength and fatigue calculation of SMC structures based on threshold strain levels for crack initiation and a damage mechanics has been developed. For comparison of designs, the damage level of damaged elements in a FE-model can be visualised.

Separate criteria are used depending on if the material is loaded in tension or compression. In particular, for a dynamic load case such as a door slam, it is shown how the peak strain level experienced by the component during the load case can be compared with the damage initiation level.

The methodology is currently limited to material that is assumed in-plane isotropic and damage development with time is not implemented.

ACKNOWLEDGEMENT
The work presented here has been done as a part of Volvo Cars CAE method development.

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