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FATIGUE ASSESSMENT UNDER CONSIDERATION OF SIZE EFFECTS AND TRANSIENT MATERIAL BEHAVIOUR

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ABSTRACT

Local strain-based fatigue design approaches usually relate fatigue phenomena to an infinitesimal small material volume, although the material parameters used to describe the stress-strain relation according to Ramberg and Osgood and the strain-life curve according to Basquin, Manson, Coffin and Morrow are commonly derived from tests with macroscopic measurements of the stress-strain state. This results in limitations of the transferability of material parameters to different geometries. As previous research indicates, a consideration of size effects may capture the influence of component geometry and load conditions on the fatigue life of components, accounting for the actual local stress-strain state as well as statistical effects. In this respect, the transient material behaviour can be of particular interest regarding the accurate evaluation of the local stress-strain state. The quality of the fatigue assessment depends mainly on the consistency of the comparison between the experimental and numerical assessed stress-strain state, which is related to the selected stress-strain behaviour.

Keywords: fatigue assessment, size effects, stress-strain behaviour, numerical simulation.

INTRODUCTION

The transient material behaviour includes cyclic hardening or softening and, depending on the load ratio and the boundary conditions of the cyclic deformation, also cyclic ratchetting and mean stress relaxation. In order to facilitate the experimental analysis of the material behaviour and the numerical fatigue assessment, a stabilization of the cyclic stress-strain behaviour is often assumed. Since the microstructure as well as the macroscopic material properties of most engineering materials change continuously during cyclic loading, this may result in a miscalculation of the actual stress-strain state, although the necessary data for a more detailed description of the material behaviour can be derived without additional effort from the fatigue test results. For this purpose, an interpretation of the stress-strain and the strain-life behaviour as continuously compatible entities is required. In order to avoid complicated mathematical formulations and extensive numerical modeling effort, a simple discretization of the stress-strain behaviour over the number of deformation cycles may be employed.

The cyclic stress-strain behaviour depends on the slip-character of the material and the load-time history. Two configurations of the slip-behaviour can be differentiated. Materials with planar slip character show only a very small tendency towards cross slip. The two dimensional dislocation structures, which are generated during the cyclic deformation, have a relatively low cyclic stability. The stress-strain behaviour in this case depends on the load magnitude only. For materials with wavy slip character, planar slip predominates during cyclic deformation with low amplitudes. The dislocations form two dimensional, but cyclically stable structures, which are referred to as persistent slip bands. With increasing load magnitude, three dimensional cell like structures are generated. The cyclic stability of the dislocation structures within materials with wavy slip character causes a dependency of the stress-strain behaviour on the load magnitude and especially on the load-sequence. As a result, the stress-strain behaviour under variable amplitude loading will differ from the stress-strain behaviour under constant amplitude loading, even if transient effects are neglected. A comparison between the cyclic stress-strain behaviour, being derived by strain-controlled testing with constant and incrementally stepped amplitudes allows a qualitative classification of the slip-character.

Taking into account the slip character as well as possible transient effect requires a definition of a cycle dependent stress-strain behaviour, in order to be able to assess the stress-strain state correctly. Considering the transfer of the stress-strain behaviour to inhomogeneously distributed stress-strain states due to notches or bending or torsional loading, it is obvious, that the stress-strain behaviour differs locally with respect to the load magnitude. Furthermore, the differences in the local stress-strain behaviour will also affect the boundary conditions of the local cyclic deformation, at least for materials which exhibit cyclic hardening or softening.

In addition to the challenging task of the accurate assessment of the cyclic stress-strain state, also size effects have to be taken into consideration. Due to the load definition within local elasto-plastic strain-based fatigue design approaches, the size effects differ substantially from the size effects, which can be defined for linear-elastic load based fatigue design approaches.

By analysis of the size effects within the linear-elastic nominal stress-approach, three types of size effects, a microstructural, mechanical and a statistical size effect, may be defined for strain-based fatigue design approaches with elasto-plastic material behaviour. Resulting from the manufacturing process, the material behaviour may be inhomogeneously distributed throughout the component, as for example within forged or selective laser melted materials. The microstructural size effect, which results from this inhomogeneity can be implemented, defining a location and orientation dependent material behaviour. The mechanical size effects may be divided into two subtypes. The first mechanical size effect is related to the notch support due to plasticity at the notch root. The second mechanical size effect refers to the material, geometry and load-sequence dependency of the local stress or strain ratio. As a consequence, the local stress-strain ratio may differ from the load ratio of the external loading. Finite element simulation with an accurate description of the location, orientation and cycle dependent material behaviour are an appropriate measure for the implementation of the mechanical size effects. The assumption of a statistical size effect is also valid for strain-based fatigue design concepts. Correlating the fatigue strength to the extension of highly loaded regions, the weakest link approach according to Weibull may be used on basis of the stress integral over the highly loaded area of the component.

The results of numerical and experimental investigations show, that the stress-strain state as well as the corresponding fatigue life is strongly affected by transient effects. In combination with an improved evaluation of the stress-strain state, the implementation of size effects may enhance the accuracy of fatigue life assessment for constant and variable amplitude loading. The application of simple models on basis of a discretization of the cyclic stress-strain behaviour is sufficient in order to improve the accuracy of the stress-strain state.

RESULTS AND CONCLUSIONS

The results from the tensile tests are shown in Fig. 1. The load-displacement curve has two different regions. The first region is nonlinear and evolves to an approximately linear region. Table 1 shows the results for the stiffness parameters E_I and E_{II}.

The most significant difference of tensile stiffness behaviour appears between Aris™ and TVTO™ on the E_I ($p=0.001$) and E_{II} ($p=0.0003$) regions.

Table 1 - Uniaxial tension test results

Tapes	E_I [(N/m)x1000]	StD	E_{II} [(N/m)x1000]	StD
Aris™	2.3898	0.2154	5.3705	0.5432
TVTO™	0.9428	0.1919	1.3083	0.2075
Uretex™	1.1367	0.1918	3.2231	0.1853
Avaulta™	1.7986	0.1925	3.7810	0.7626
Auto Suture™	1.0507	0.0766	2.2624	0.2658

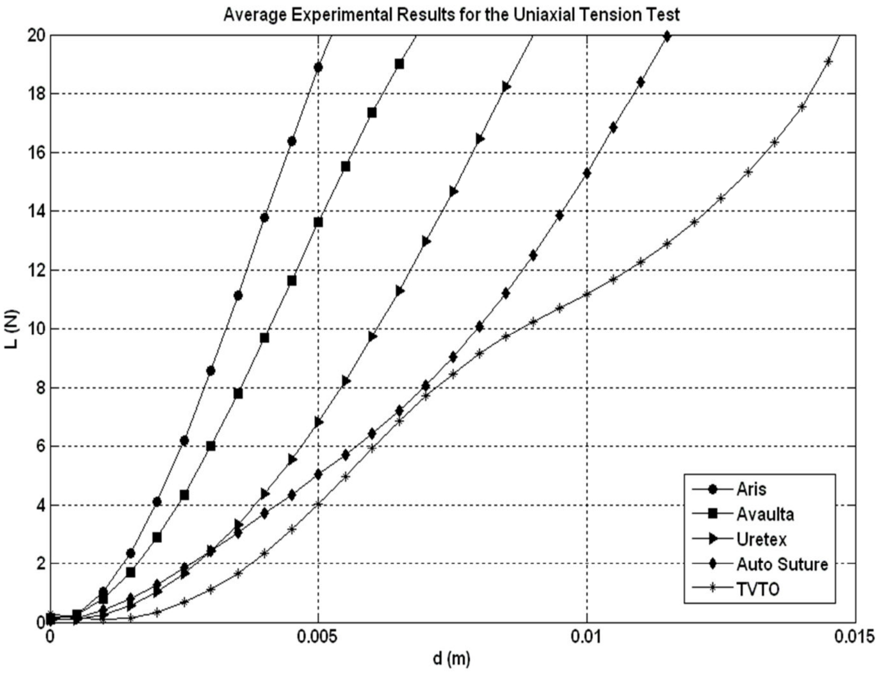

Fig. 1 - Tensile test results

This study shows that there are substantial differences on the mechanical properties of different urogynecology meshes. Further tests should be performed in order to analyze other mechanical properties, such as flexural properties.

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