On the Numerical Modelling of Local Stress-Strain Sequences under Complex Constant/Variable Amplitude Fatigue Loading

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Abstract. The present paper aims to assess the accuracy and reliability of commercial Finite Element (FE) software ANSYS® in modelling the local elastoplastic stress-strain behaviour of metals subjected to uniaxial/multiaxial constant/variable amplitude loading. The accuracy and reliability of the investigated numerical approach was checked against numerous experimental results taken from the technical literature and generated by testing, under a variety of complex loading paths, different metals. Further, the hysteresis loops being determined numerically were compared (in terms of magnitude and profile) also with those estimated using the well-known approach due to Jiang and Sehitoglu [1]. This systematic validation exercise allowed us to prove that, under proportional loading paths, the use of the procedure that is implemented in FE code ANSYS® returns results that are characterised (from an engineering point of view) by an adequate level of accuracy.

Introduction

Evaluation and assessment of fatigue lifetime of components are an integral part of the design process, with this problem becoming very complex when the elsto-plastic behaviour of metals has to be modelled explicitly under time-variable loading [2-5]. In particular, the correct estimation of the local elasto-plastic stress-strain states is a fundamental step in quantifying the extend of fatigue damage associated with the in-service load history being assessed. In this context, certainly the most accurate way to determine the required local stress-strain information is by running appropriate experiments. Unfortunately, this is not always doable due to tight restrictions in terms of both time and financial resources, with numerical analyses being the only way to estimate the necessary stress vs. strain hysteresis loops. In this challenging scenario, the present paper aims to investigate commercial FE software ANSYS®'s capability of modelling the local elastoplastic stress-strain behaviour of metals subjected to uniaxial/multiaxial constant/variable amplitude multiaxial fatigue loading.

FE Modelling

Plain cylindrical shafts were modelled using FE software ANSYS®. The required material properties as well as the considered experimental results were taken from Refs [6-11]. The elasto-plastic cyclic properties required to model the mechanical behaviour of the materials being investigated were described by inputting solely the constants of the corresponding uniaxial stabilised stress-strain curves. The cyclic behaviour was estimated by assuming that metallic materials obey a kinematic hardening rule, with this holding true independently from the degree of multiaxiality and non-proportionality characterising the load history under investigation.

The validation exercise being carried out involved both constant and variable amplitude loading paths. Further, uniaxial as well as in-phase and out-of-phase biaxial load histories were considered.

Finally, the hysteresis loops being estimated numerically were compared not only with the corresponding experimental stress vs. strain paths, but also with those estimated using the well-known approach devised by Jiang and Sehitoglu [1].

Result and Discussion

Figure 1 summarises some of the results that were obtained by using FE software ANSYS®. In particular, for every case being considered, the different charts of Figure 1 report not only the hysteresis loops of interest, but also the characteristics of the considered load histories.
The different analyses that were performed suggest that a good agreement is obtained not only under pure uniaxial and pure torsional loading, but also under proportional biaxial load histories. In contrast, FE software ANSYS® is seen to return quite inaccurate results when this software is used to estimate hysteresis loops resulting from non-proportional biaxial load histories. This can be ascribed to the fact that FE code ANSYS® is not capable of correctly modelling the effect of non-proportional hardening.

Conclusions

1. FE software ANSYS® is successful in modelling the elasto-plastic cyclic behaviour of metals under pure uniaxial loading, under pure torsion, as well as under proportional biaxial loading.
2. Since this commercial FE code is not designed to take into account explicitly the effect due to non-proportional hardening, attention must be paid when using it to design components subjected to in-service non-proportional load histories.
3. Jiang and Sehitoglu's approach [1] is seen to return accurate estimates, with this holding true independently from the complexity of the loading path being assessed.

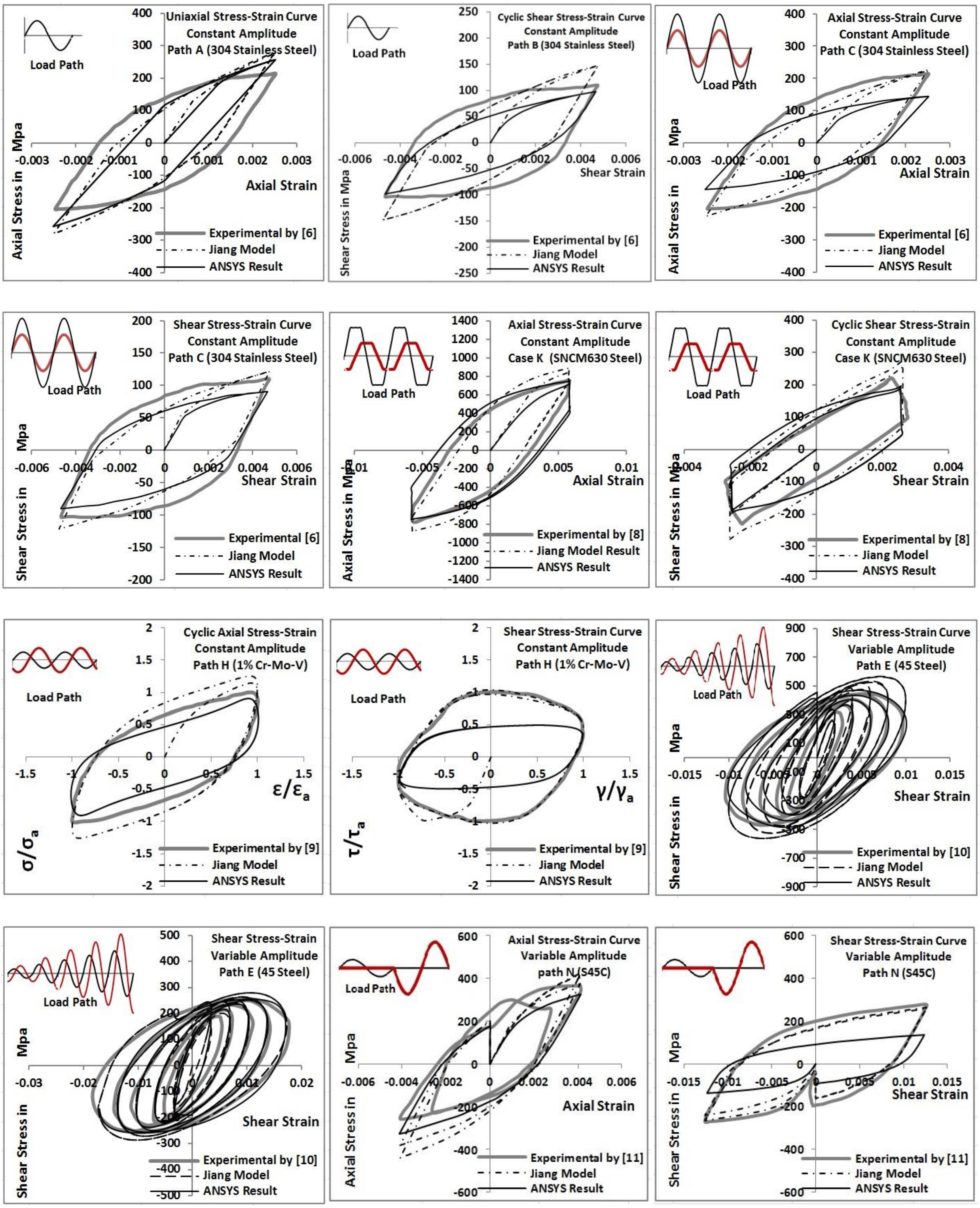

Fig. 1 Generated hysteresis loops compare with the experimentally reported and Jiang's model

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