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A comparative study between conventional and elevated temperature creep autofrettage

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Abstract

This paper presents a comparative study between conventional hydraulic and elevated temperature autofrettage. For modelling of both methods advanced plasticity and creep material models are used. The main governing equations for the models are presented as well. A beneficial influence of compressive residual stresses induced by both methods is demonstrated on a benchmark problem of cross bored block. The effectiveness and applicability of the two methods are estimated by conduction of compressive residual stress analysis and crack arrest modeling. Numerical simulation of the cyclic plasticity and creep problems are carried out by means of FEM in ANSYS Workbench with FORTRAN user-programmable subroutines for material model incorporating custom equations.

Keywords:
Crack arrest, Creep autofrettage, Finite Element Analysis, Plasticity, Compressive residual stress

1. Introduction

Application of the autofrettage processes has become a useful tool of increasing the fatigue resistance for many high pressure components working in dynamic conditions. Nowadays, several types of autofrettage such as hydraulic, swage, thermal autofrettage and combination of autofrettage with shrink fitting technology are extensively used in different industries. This paper is mainly concentrated on the effect of hydraulic autofrettage which is applicable for a huge variety of high pressure parts with highly stressed locations due to sharp corners of bore intersections. The main idea of hydraulic autofrettage is to apply high pressure to the internal surface of a high pressure component in order to induce a plastic strain of required values. With unloading the elastic layers of a component start shrinking the plastically deformed layers thereby inducing compressive stresses. There have been numerous studies regarding to hydraulic autofrettage modelling starting from a simple analytical close solution (Adibi-Asl and Livieri, 2006; Wahi et al., 2011; Trojnacki and Krasiński, 2014) and ending with quite comprehensive models which include accu-

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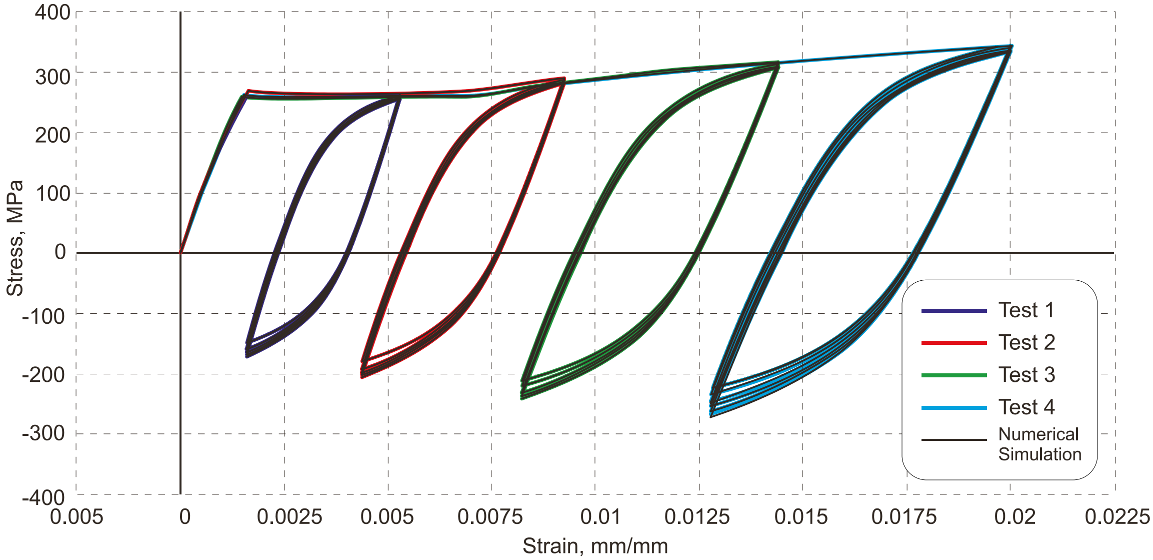

Fig. 1. Cyclic plasticity material response.

rate material behavior and fatigue lifetime prediction (Jahed et al., 2006; Parker and Underwood, 1999). Nevertheless, such research questions as the accurate material behavior modelling and fatigue lifetime prediction of autofrettaged components with high stress concentration locations are still open.

Conventional hydraulic autofrettage assumes application of overload pressure at ambient temperature. However, studies by Berman and Pai (1967, 1969) showed that application of autofrettage pressure at elevated temperature can provide some benefits over conventional ambient temperature autofrettage. Overload pressure in the case of elevated temperature autofrettage is significantly lower than that pressure for hydraulic autofrettage as inelastic creep strains are induced at a smaller level of stresses. This may be more favorable for the cases where the application of very high pressure in autofrettage assemblies may cause structural damage. That type of autofrettage can also provide a deeper level of compressive residual stresses compared to conventional autofrettage. In spite of the potential benefits of creep autofrettage, this problem has not got much attention since the first publications. This may be explained by a lack of the knowledge of the material properties under conditions of creep deformation and modelling techniques which are able to simulate creep compressive residual stresses. One of the objectives of this study is, therefore, to extend conventional hydraulic autofrettage to an elevated temperature autofrettage application with inducing creep strains.

Another problem for the autofrettage processes in general is prediction of the fatigue lifetime under the influence of compressive residual stresses. Despite the fact that compressive residual stresses can significantly improve the fatigue lifetime of high pressure components the mechanism of fatigue failure under the influence of compressive residual stresses is not always clear. The dominant part of the fatigue lifetime in components without compressive residual stresses is the crack initiation stage and as soon as a crack is initiated at the surface it immediately propagates inside a component causing fatigue failure. Time for the crack propagation in this case varies from tens to hundreds of cycles which is significantly less than crack initiation time. However, this may not be the case of components with high compressive residual stresses where an initiated crack can be arrested at some point of the propagation.

Herz et al. (2011) show that the prediction of the fatigue failure should depend on the mechanism of failure associated with the presence of compressive residual stresses. For the case of component testing without introducing compressive residual stresses the calculation of crack initiation lives according to local strain based approach had a close prediction to the experimental results. Calculation of the crack propagation life in this case showed negligible effect compared to the initiation life. The situation is different for the case of testing samples with induced compressive residual stresses. A better prediction of fatigue failure is achieved by the crack growth calculation and it is clearly demonstrated that the fatigue endurance limit is related to the crack arrest phenomenon. The crack arrest phenomenon is also more likely to happen in the case of high pressure components working in aggressive corrosion environments, where cracks are initiated at significantly lower levels of stress compared to non-corrosive environments.