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Influence of the pressure holding time on strain generation in fuel injection lines

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ABSTRACT

An influence of the pressure holding time on residual strain generation during the autofrettage process was studied experimentally for the first time in the present work. It is the state of the art that fuel injection lines are held at the autofrettage pressure for only a few seconds in an industrial production. In doing so, it is assumed that a desirable residual stress–strain pattern is generated. However, the results of the experimental investigations outlined in this work indicated that completion of the plastic deformation caused by the autofrettage process and generation of the desirable stress–strain pattern require a much longer period. As shown, a third-order polynomial equation best described the interdependence between the time required for the completion of the process, the corresponding autofrettage pressure and the generated strain state. The method presented can be used as a tool for the determination of the optimal autofrettage process parameters in industrial production of fuel injection lines.

1. Introduction

Modern high pressure fuel injection systems installed in engines provide a highly efficient combustion process accompanied by low emissions of exhaust gases and an impressive level of dynamic response. The design and development of mechanical components for such systems pose a great challenge, since they have to operate under extremely high fluctuating pressures (e.g. up to 2000 bar) for a long lifetime (more than 1000 injections per minute). The permanent change between a higher and a lower pressure causes a cyclic stress in the material that leads to fatigue of the material until a failure of the component occurs.

In cases where a good capability for high loading and an enhanced lifetime of components are required, the components are autofrettaged in the production process. An autofrettage process is a manufacturing procedure wherein the component is subjected to a static internal pressure far beyond the intended operating pressure in order to induce a partial yielding of the component. After a short period of time, the component is unloaded and the required permanent plastic deformation is reached. The plastic deformation is accompanied by the generation of residual stresses in the component. The objective of the autofrettage treatment is to obtain a favourable residual stress pattern which brings beneficial effects under operating conditions. By application of the autofrettage treatment, the static loading capability of components can be increased due to the strain hardening effect which takes place during the process [1]. Furthermore, the residual stress pattern reduces crack initiation, retards the fatigue crack growth rate and consequently increases the fatigue limit of components [2–4].

Although the first deliberate application of the autofrettage principle dates back to the beginning of the twentieth century, the autofrettage process and its effects on high pressure components still remain mostly unknown. An intention of the present work was an investigation of the influence of the pressure holding time on stress–strain generation during the autofrettage process. The influence of the pressure holding time on the final effects of the autofrettage process has not been considered until now; this influence was studied experimentally for the first time in this work. Namely, an industrial production of components relies either on a limited analytical steady solution [5–7] or on simple numerical computations using steady models [8,9] which do not consider the influence of the holding time on the plastic deformation process. It is the state of the art that fuel injection lines are held at the pressure for only a few seconds (approximately 3–10 s) during the autofrettage process. In doing so, it is assumed that a required stress–strain pattern is generated. However, the results of the experimental investigations outlined in this work revealed that completion of the plastic deformation caused by the autofrettage process requires a much longer period, owing to the time-dependent nature of the plastic deformation in the inner layers of a fuel line. This may explain the frequent damage to and unexpected

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