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EVALUATING THE INFLUENCE OF SHRINKAGES IN NODULAR CAST IRON ON FATIGUE STRENGTH

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ABSTRACT

During the design of thick-walled components made of nodular cast iron the local fatigue strength of the materials used needs to be known properly. This includes stress and strain based fatigue information for the evaluation of the local material behaviour in notches as well as the assessment of local imperfections in the material. In the latter case measures of non-destructive testing (NDT) are used to evaluate the size, the position and the density of the imperfections during the quality management process. In the following this information needs to be transferred into a fatigue assessment concept to assure the components safety.

Keywords: fatigue strength, nodular cast iron, shrinkages, thick-walled.

INTRODUCTION

For the design of thick-walled nodular cast iron components the fatigue assessment especially in the context of local imperfections in the material is a challenging task. Not only the cyclic material behaviour of the sound baseline material but also the cyclic behaviour of materials with imperfections like shrinkages, dross and chunky graphite needs to be considered during the design process of cast iron components. In addition to that, new materials like solid solutions strengthened alloys offer new possibilities in lightweight design but need to be assessed concerning their fatigue strength and elastic-plastic material behaviour. If a safe and reproducible fatigue assessment for any component cannot be performed and a secure usage is therefore not given, the cast components are mostly rejected, what leads to a loss of additional material, energy and money for recasting the components.

In this context three nodular cast iron materials are compared concerning their cyclic material and fatigue behaviour as well as their potential for a lightweight design based on stress and strain controlled tests. To develop an optimal and individual fatigue design method for cast components with local material imperfections present, the component's local fatigue strength needs to be combined with information from non-destructive testing (NDT), since a removal of specimens is mostly not possible. For this purpose a method is described, that uses information of ultrasonic and X-ray analysis as well as the given fatigue strength of the baseline material to conduct a fatigue assessment of local shrinkages in nodular cast iron. The method is based on the local density measured by NDT and its correlation to the fatigue notch factor of the shrinkages.

RESULTS AND CONCLUSIONS

During the work specimens of EN-GJS-400-18U-LT, EN GJS-450-18 and EN-GJS-700-2 are taken from thick-walled cast block containing large shrinkages. By a position and density ρ

measurement of the shrinkages inside the cast blocks by the ultrasonic technique Sampling Phased Array, a clear distinction between volumes with and without shrinkages can be conducted for the specimen removal from the cast blocks. For the characterization of the cyclic behaviour of the sound material, cyclic stress-strain curves, strain- and stress-life curves as well as mean-stress sensitivities were determined for stress ratios $R_\sigma = -1$, $R_\sigma = 0$ and a strain ratio of $R_\varepsilon = -1$. For all three materials a cyclic hardening effect can be shown by the strain-controlled tests indicating a certain lightweight potential by using nodular cast iron. Based on the results of the stress controlled fatigue tests EN-GJS-700-2 shows the highest fatigue strength, followed by the solid solution strengthened EN-GJS-450-18 and EN-GJS-400-18U-LT. All materials show mean-stress sensitivities between $0.37 \leq M \leq 0.55$ and thus much higher values than suggested by design standards as e.g. the FKM guideline.

To determine the fatigue strength of the shrinkages, fatigue specimens with a test diameter of d = 15 mm are removed from these volumes. For a non-destructive characterization of the shrinkages, an extensometer is mounted on the specimen's test volume to determine the so called virtual Young's modulus E_f meaning the stiffness of the shrinkages. Afterwards each specimen with shrinkages is cyclically tested under fully reversed loading, $R_\sigma = -1$.

It is shown that a linear correlation exists between the density ρ measured in the fatigue critical material volume of the specimens and the virtual Young's modulus E_f determined for each fatigue specimen. Thus, a connection between the density ρ obtained by NDT and a mechanical value E_f is given. Furthermore, a second linear correlation between the fatigue notch factor of the shrinkages K_{fs} and E_f is determined. Based on that, for $R_\sigma = -1$, a transformation of the nominal stress amplitudes of the fatigue specimens with shrinkages by a reference stress-life curve for the sound material and the virtual Young's modulus E_f is developed, enabling an estimation of the fatigue strength of the fatigue specimens with shrinkages. For this purpose a fatigue strength related to a required fatigue life is determined from the reference stress-life curve. Depending on the shrinkage related fatigue notch factor K_{fs} and an additional safety factor S_{Sh} this fatigue strength is reduced.

For an evaluation of the component's fatigue strength it is now possible to determine a local value for E_f by evaluating the local density ρ by means of e.g. ultrasonic technique Sampling Phased Array. From the local density ρ a local fatigue notch factor K_{fs} is determined. The main advantage of the new, local method is the manageable effort for implementation. Only a reference stress-life curve for the sound material condition needs to be on hand, while an investigation of the cast component's critical parts needs to be done with the ultrasonic technique Sampling Phased Array to determine the local density. The new method shows a connection between local stress and local fatigue strength.

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