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# Influence of Different Load Histories on the Cyclic Material Behavior of Nodular Cast Iron for Thick-walled Application

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**This article discusses the cyclic material behavior—in the form of stress–life, strain–life, and cyclic stress–strain curves—of different nodular cast iron materials derived from specimens taken from cast blocks and a main frame of a wind energy turbine. Results are shown for both static and cyclic strain-controlled tests performed at room temperature under constant and variable amplitude loading for alternating loading, respectively. The load-time histories used for the tests under variable amplitude loading are taken from a wind turbine hub and main frame. A negative overload was introduced to check the influence of overloads on the fatigue strength of the materials, provoking positive mean stresses in the specimen and thus a shorter lifetime.**

## NOMENCLATURE

| | |
|---|---|
| $\bar{N}_r$ | Cycles to rupture under variable amplitude loading |
| $A_5$ | Breaking strain (in %) |
| $b$, $b_1$, $b_2$, $b_3$ | Fatigue strength exponent |
| $c$ | Fatigue ductility exponent |
| $d$ | Diameter of the specimen (in mm) |
| $E$ | Young's modulus (in GPa) |
| $f$ | Test frequency (in Hz) |
| $H$ | Cumulative frequency |
| $H_0$ | Number of cycles of the subsequence |
| $\mathrm{HBV}_{90\%}$ | Highly stressed volume in the component, in which the maximum load is reduced from 100% to 90% (in $mm^3$) |
| $K'$ | Cyclic hardening coefficient (in MPa) |
| $K_t$ | Stress concentration factor |
| $M$ | Mean stress sensitivity |
| $N$ | Lifetime (cycles) |
| $n'$ | Cyclic hardening exponent |
| $N_{\mathrm{lim}}$ | Limit number of cycles |
| $N_r$ | Cycles to rupture under constant amplitude loading |
| $R'_{p0,2}$ | Cyclic yield strength (in MPa) |
| $R_m$ | Tensile strength (in MPa) |
| $R_{p0,2}$ | Yield strength (in MPa) |
| $R_\varepsilon$ | Load ratio under constand amplitude loading |
| $\bar{R}_\varepsilon$ | Load ratio under variable amplitude loading |
| $\varepsilon_{a,e}$ | Elastic strain (in %) |
| $\varepsilon_{a,p}$ | Plastic strain (in %) |
| $\varepsilon_{a,t}$ | Total strain under constant amplitude loading (in %) |
| $t$; $\bar{\varepsilon}_a$ | Total stain under variable amplitude loading (in %) |
| $\varepsilon'_f$ | Fatigue ductility coefficient (in m/m) |
| $\sigma'_{f1}$, $\sigma'_{f2}$, $\sigma'_{f3}$ | Fatigue strength coefficient (in MPa) |

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KEY WORDS: Nodular cast iron, wind energy, fatigue, cyclic material behavior, thick-walled, overload.

## INTRODUCTION

For a reduction in the weight of and an increase in both the power and utilization of nodular cast iron components of wind energy turbines and other heavy industry parts, material needs to withstand locally higher loads. Especially when one is evaluating the influence of overloads on the structure of thick-walled wind energy components made of nodular cast iron causing local elastic-plastic deformations, the cyclic, elastic-plastic material behavior and its development under cyclic loading are important points to consider during component design.

To assess the material's local elastic-plastic material behavior, strain-controlled fatigue tests were performed at alternating loading, $R_\varepsilon = -1$, with unnotched specimens removed from cast blocks and components of wind energy turbines made from EN-GJS-400-18U-LT, EN-GJS-400-15, EN-GJS-450-18, EN-GJS-700-2, and ADI-800. Fatigue tests were performed based on constant amplitude and variable amplitude loading to determine their influence on the elastic-plastic material behavior. For the fatigue tests under variable amplitude loading, two load-time histories, which were derived from different single-load cases measured on a hub and main frame of a wind energy turbine, were used. To analyze the influence of an overload during usage, an additional test series was run in which a maximum overload of 1.0% under tensile loading ($\bar{R}_\varepsilon = -\infty$) was added in the load sequences and the results compared with those without overload.

For all tested materials, a change in the stress–strain behavior could be determined based on the fatigue tests under constant amplitude loading, as a result of a cyclic hardening of the materials during cyclic loading. Furthermore, the fatigue tests under variable amplitude loading showed a lifetime reduction when applying an additional overload right at the beginning of each single fatigue test.

## PREVIOUS WORK

To date, not only smaller but also thick-walled components made from nodular cast iron are subjected to local elastic-plastic strains, leading to a need for local strain-based design approaches, especially when the influence of varying design load cases needs to be assessed during the design phase in terms of fatigue and crack propagation. However, there is still a lack of inclusion and assessment of the influence of overloads during the usage of, for