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High-Silicon Nodular Cast Iron for Lightweight Optimized Wind Energy Components

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The increasing need for lighter components for wind energy application led to an increasing afford in the foundries to develop high-strength nodular cast iron materials (GJS) offering both high strength and high ductility. High-silicon nodular cast iron is one of those developments. Nevertheless, until now, to the best of our knowledge, no real characterization of these materials in terms of cyclic material behavior has been done. Thus, in this paper, one of the high-silicon nodular cast iron grades, EN-GJS-500-14, was investigated to determine the technological, statistical, and geometrical size effects for a proper component design a lifetime assessment.

INTRODUCTION

Components for wind energy turbines, heavy industry, or automotive application made of nodular cast iron have growing performance requirements. In addition to the classic ferritic and pearlitic nodular graphite cast iron, new high-silicon solid-solution-strengthened grades have been developed. These grades with a full ferritic matrix provide higher quasistatic properties, especially a higher elongation at break. Nevertheless, for the standardized silicon nodular cast iron grades EN-GJS-450-18, EN-GJS-500-14, and EN-GJS-600-10, there is still a big lack of knowledge regarding their fatigue and fracture mechanical behavior. Thus, in this research project, we, in cooperation with partners from various branches of industry, especially the wind energy sector, investigate the behavior of cyclic material.

For this purpose, casting samples and serial components of different wall thicknesses were cast from nodular cast iron grades EN-GJS-450-18, EN-GJS-500-14, and EN-GJS-600-10. Specimens of different sizes were removed from these casting samples and components to determine the cyclic material behavior by stress- and strain-controlled fatigue tests. The aim of the investigation was to determine the technological (wall thickness), geometrical, and statistical size (specimen size) effects for the three different materials and to combine this information in a fatigue assessment concept for all types of small and large cast components. In addition, all gathered data were compared with casting simulation. This enables the evaluation of the local fatigue strength already in the design phase by providing fatigue data by means of casting simulation.

To reduce the weight and increase both the power and the utilization of nodular cast iron components, high-silicon grades have been developed in recent years (Mikoleizik and Kleinkröger, 2012; Stets et al., 2014; European Committee for Standardization (CEN), 2019). The higher silicon content enables a higher tensile strength and thus fatigue strength by a solid solution strengthening of the matrix while still having a comparably ductile ferritic matrix. The aim of those nodular cast iron or solid-solution-strengthened ductile iron (SSDI) grades for application in wind energy turbines, other heavy industry parts, and smaller automotive-related components is to replace ferritic-pearlitic and purely pearlitic grades such as EN-GJS-700-2 because of their lower elongation and ductility (CEN, 2019). Even so, the occurrence of graphite degenerations such as chunky graphite, especially in thick-walled components, is likely promoted by the higher silicon content (Stets et al., 2014); there is strong interest in using those SSDI grades especially in wind energy application.

Nevertheless, there is still a dearth of knowledge regarding the fatigue behavior of European-wide standardized grades EN-GJS-450-18, EN-GJS-500-14, and EN-GJS-600-10 (CEN, 2019). In particular, the influence of the size effects (Kloos, 1976) on fatigue strength and the cyclic material behavior for SSDI are more or less unknown. So far, no comparisons between the three grades for the same cooling rates and different specimen geometries have been conducted to determine the influence of casting skin, wall thickness, solidification times, load situation, and size effects.

To assess the material's microstructure dependent material behavior, stress-controlled fatigue tests were performed at alternating loading, $R_\sigma = -1$, as well as tensile loading, $R_\sigma = 0$ and $R_\sigma = 0.5$, with notched and unnotched specimens removed from cast samples and two wind energy components (torque arm and plate) related to the thickness of wind energy turbines made from EN-GJS-500-14.

PREVIOUS WORK

To our knowledge, the cyclic material behavior for solid-solution-strengthened GJS so far has not been investigated in depth, but there are related studies. For example, Stets et al. (2014) conducted fatigue tests on EN-GJS-500-14 but gave no information about the specimen size. A wide range of cyclic material investigations on different specimen sizes was done in Mikoleizik and Kleinkröger (2012) on EN-GJS-450-18 for large cast components. For unnotched specimens with a test diameter of 15 mm, a nominal stress amplitude at $N_{\lim} = 1 \cdot 10^7$ cycles of 151 MPa was determined. But no detailed investigation of the local microstructure in relation to the highly stressed volume was done.

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