Shrinkage-induced gas porosity model from a fatigue prediction point of view: a case study for nodular cast iron

Joona Vaara[*], **Jarkko Laine**[*], **Tero Frondelius**[*,#]

[*] R&D and Engineering
Wärtsilä Finland Oy
P.O.Box 244, 65101 Vaasa, Finland
e-mail: joona.vaara@wartsila.com

[#] University of Oulu
Materials and Mechanical Engineering
Pentti Kaiteran katu 1, 90014 University of Oulu, Finland
e-mail: tero.frondelius@oulu.fi

ABSTRACT

The fatigue properties of nodular cast iron heavily depend on the success of the casting process. Recently, the defect-based fatigue limit prediction by Murakami and Endo [3] has been used to describe the fatigue of ferritic-pearlitic nodular cast irons. The graphite nodules and micro-shrinkage cavities act as typical crack initiators in the experimental observations in the literature. The sizes of both defect types have been quantified by experimental microscopy. A recent model by the authors predicts the sizes of graphite nodules and clusters from input based on casting simulation. The empirical Niyama criterion [4] is commonly implemented in the casting simulation software. The Niyama criterion yields a simple qualitative comparison of castings, but a thorough mapping of the model response to experimental findings would be required for quantitative prediction. This is especially true for nodular cast iron, where the graphite expansion occurs during solidification. Recently, a physics-based shrinkage-induced gas porosity model [1] has looked promising to predict the micro-shrinkage porosities in nodular cast irons.

Here, we will study the shrinkage-induced gas porosity model's suitability in light of a relatively well-documented historical fatigue test series [2]. In this fatigue test series, specimens were cut from a heavy-duty marine engine's cylinder head, and approximately 80% of the specimens failed from a shrinkage porosity. Casting simulation and assessing the competition of other failure modes [5] will be of high importance for the study's success. The goal would be to predict the risk of the fatigue limit being defined by the shrinkage porosities based on casting simulation to avoid non-conservative dimensioning. The stochastic nature of the pore nucleation with respect to the Poisson process and extreme value statistics need to be looked into.

Keywords: nodular cast iron, fatigue, micro-porosity, casting, modelling.

REFERENCES

[1] Kweon, E., Roh, D., Kim, S., and Stefanescu, D. Computational modeling of shrinkage porosity formation in spheroidal graphite iron: a proof of concept and experimental validation. *International Journal of Metalcasting 14*, 3 (2020), 601–609.

[2] Marquis, G., Rabb, R., and Siivonen, L. Endurance limit design of spheroidal graphite cast iron components based on natural defects. *ASTM SPECIAL TECHNICAL PUBLICATION 1372* (2000), 411–426.

[3] Murakami, Y., and Endo, M. Effects of defects, inclusions and inhomogeneities on fatigue strength. *International journal of fatigue 16*, 3 (1994), 163–182.

[4] Niyama, E. A method of shrinkage prediction and its application to steel casting practice. *Imono 54*, 8 (1982), 507–517.

[5] Vaara, J., Väntänen, M., Kämäräinen, P., Kemppainen, J., and Frondelius, T. Bayesian analysis of critical fatigue failure sources. *International journal of fatigue 130* (2020), 105282.