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Published in:
Conference proceedings of the 12th International Symposium on the Science and Processing of Cast Iron

Published: 09/11/2021

Document Version
Peer-reviewed accepted author manuscript, also known as Final accepted manuscript or Post-print

Please cite the original version:
Jalava, K., Mourujärvi, A., Laine, J., & Orkas, J. (2021). Cast iron selection based on design requirements of thermomechanically loaded applications and its' foundry challenges. In *Conference proceedings of the 12th International Symposium on the Science and Processing of Cast Iron* Muroran Institute of Technology.

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Cast iron selection based on design requirements of thermomechanically loaded applications and its' foundry challenges

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Abstract

Cast irons envelop a substantial property window both in mechanical and thermal properties. Typically, in standards, grades are defined through mechanical properties, leaving a lot of variables to be chosen and adjusted from a foundry's perspective. With similar strength levels, cast irons can contain a wide range of microstructural compositions, types and volume of graphite. These have clear influence on properties other than tensile strength. For high-performance materials like cast irons, the selection of grades should be based more on properties required by present-day engineering design needs and procedures. This work explores material selection from a thermomechanical end-use perspective, taking a view on microstructural composition, alloying levels and other factors traditionally not requested by the end-user side. Naturally, such an approach brings certain challenges and limitations with it into a foundry process. This work views the proposed approach from the foundry viewpoint and discusses actions that could be done to make it into reality.

Keywords: ductile iron, thermal properties, mechanical properties, material selection, foundry process

1. Introduction

The whole material group of cast irons envelops a substantial property window both in mechanical and thermal properties, arising from various achievable forms of graphite, microstructural constituents, and levels of alloying elements. Typically, in material standards, grades are defined through mechanical properties such as tensile strength and elongation, leaving a lot of variables to be chosen and adjusted from a foundry's perspective. With similar strength levels, cast irons can contain a wide range of microstructural compositions, types and volume of graphite through differing carbon equivalents, levels of alloying elements from specific melt treatments and so forth. These kinds of factors have clear influence on factors other than tensile strength. For comprehensively high-performance capable materials like cast irons, the selection of grades should be based more on properties required by present-day engineering design needs and procedures. For example, Zanardi et al. proposed a reclassification of ductile irons for static and cyclic load case analysis [1] based on a more comprehensive set of properties compared to traditional specifications. The limitations in current standards can be broadly summarized as follows; chemical compositions commonly used for grade EN GJS 500-14 ductile iron would meet the requirements of grade EN GJS 500-7 but differ drastically in properties other than tensile strength and elongation.

In the case of thermomechanically loaded applications, such as power generation, strength is an important aspect but far from an only priority. To mitigate thermomechanical fatigue, prioritizing thermal conduction in combination with strength may offer means to an end [2]. Thus, to view material selection from a thermomechanical end-use perspective, an analysis of microstructural composition, alloying levels and other factors traditionally not so often requested by the end-user side need to be made. Properties connected to thermal conduction combined with yield strength in use-critical areas of components meets the needs of a material-minded engineer much better than just choosing a grade with approximate or probable secondary properties. Naturally, such an approach brings certain challenges and limitations with it into a foundry process and procurement chains.

2. Methodology

For thermomechanically loaded components, design parameters need to be expanded to thermal resistance and conduction phenomena. Thermal loads depend on component geometries and material parameters, such as thermal expansion and conductivity. The effects of thermal loading on fatigue lifetime can be affected by various means, such as; increasing material strength to increase tolerance to low-cycle fatigue, increasing material thermal conductivity and subsequently decreasing thermal gradients, decreasing thermal expansion coefficient and thus thermal loads. Therefore, optimisation of mechanical properties and thermal conduction are essential tools for engineers designing thermally loaded components.

The effects of silicon content and pearlite fraction on ductile iron thermal conductivity have been studied previously [3, 4]. Fig. 1 shows the relation between

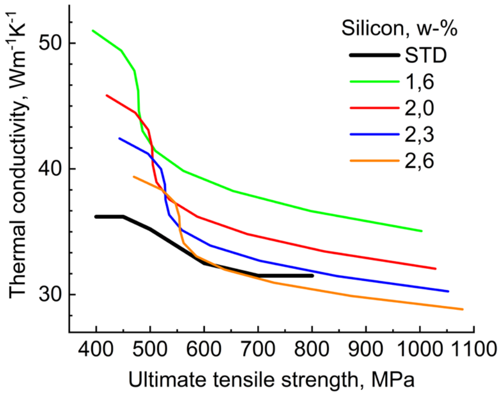

Fig. 1 Thermal conductivity vs. tensile strength at different silicon contents and pearlite fractions, at 200 °C

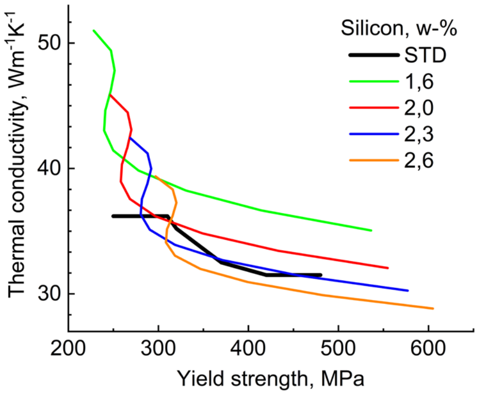

Fig. 2 Thermal conductivity vs. yield strength at different silicon contents and pearlite fractions, at 200 °C

thermal conductivity and tensile strength at 200 °C with various silicon contents (series) and pearlite fractions (0 – 100 %, increasing strength). Fig. 2 shows the same in relation to yield strength. STD series shows the available limited indicative values from EN 1563 table E1 at room temperature and thermal conductivity at 300 °C. With such data, selection could be made with parameters like silicon and pearlite content, corresponding to a suitable combination of strength and thermal properties. Ultimately, selection based on composition in relation to another property, undoubtedly common with many cast materials groups.

3. Discussion

Use of the outlined methodology or the like requires a new perspective on production of cast irons from foundries. Traditionally, the gauged requirements concern yield and tensile strength, along with elongation. Additionally, setting quality levels of surface and internal defects are industry wide practices. Traditionally the inhibition of defect formation has been achieved through control of parameters like carbon equivalent and adjustment of mechanical properties with alteration of pearlite content and the like. In a material property-based design, the objective is to achieve certain local properties, which are not commonly tested from supplied castings. This all means that the approach limits the traditional avenues for controlling internal defects from the foundry perspective.

As such, local material property approaches require good co-operation and communication between supplier and procurer. Leading-edge foundries use various casting simulation software to optimize the quality and properties of castings in critical locations. One priority is to optimize clients plans to work with the foundry's own production process. E.g. available moulding flask sizes, used moulding aggregate and binder systems affect solidification, defect formation and microstructures. After simulations and casting process design, it's paramount to validate the process and resulting properties with a prototype batch and change the process or composition if needed, more than ever before. Naturally, the physical size of castings and batch volumes are key aspects whether a product-specific material optimization can be economically viable for a foundry. This also affects whether there is interest to develop competence to reach such a goal. For a cast iron foundry specifically, it's decisive to find ways to confirm the process parameters requested by the client result in the desired properties and how situations where such are not reached, are handled. Ultimately, these should not be impassable challenges for a material property-based design and production. On the contrary, such approaches can open new possibilities and markets for foundries open to change.

4. Conclusions

Cast iron selection based on composition and microstructure would allow enhanced applicational properties. However, use of said criteria limit foundries traditional process control tools and capabilities. Increased knowledge of cast iron formation and simulation tools can present a solution.

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