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WHITE PAPER

CAST OPTIMIZATION BY MANUFACTURING SIMULATIONS TOOLS (COST)

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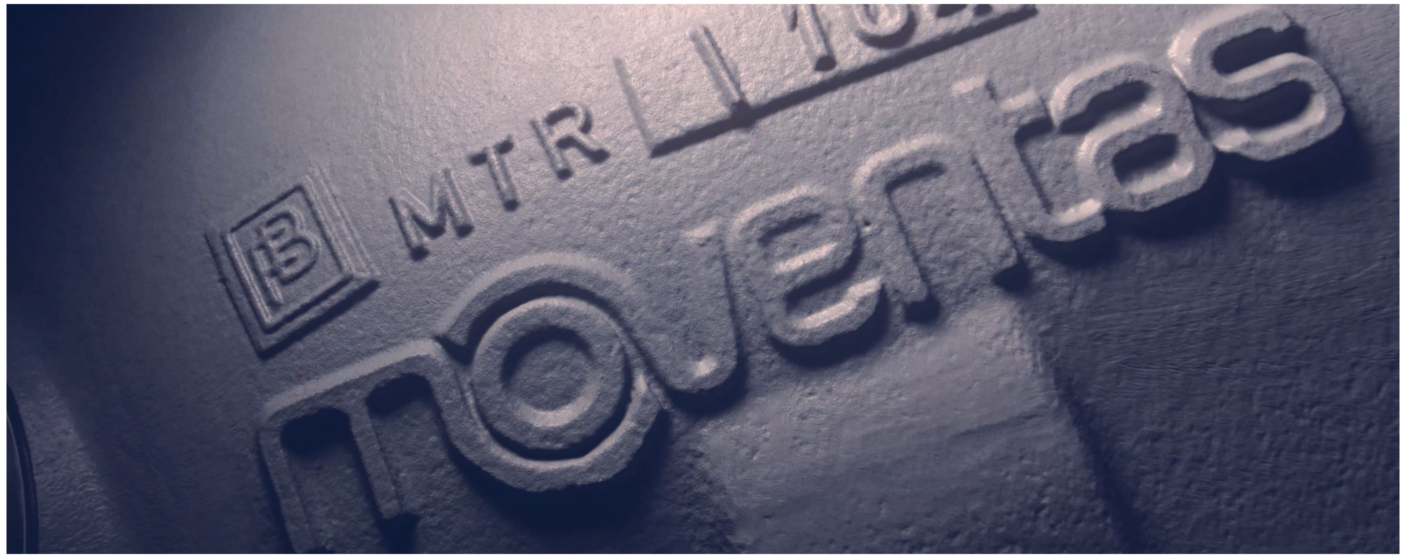
1. Abstract

The task of this white paper and of the original M.Sc. thesis was to find correlation between the capabilities of casting simulation programs, and the reality of large spheroidal graphite cast iron castings. The thesis spearheaded one of Moventas' brand-new research projects from start to finish, with the help of Moventas team of top experts of the field. Cast optimization by manufacturing Simulation Tools (COST) was proposed to answer the growing need in gearbox design to get more out of the material.

This topic is of great importance due to the growing need in gearbox design(s) to optimize material usage. At its core, the mechanical properties data used for the finite element method (FEM) analysis is based on values provided in the respective standard. This value is often a safe value, referring to lowest expected properties in the casting. Using simulation software to predict local mechanical properties in the casting could allow for higher design stresses for cast components, thus allowing optimized design.

Correlations were found in mechanical properties and simulation, but values need to be adjusted to fully correspond. The effect of pearlitizing in SGI (spheroidal graphite cast iron) was also evaluated. Correlation between nodule count and mechanical properties was also found. Similar procedure as presented in this thesis can be implemented with other foundries, where cast simulations are compared to real-life mechanical testing results of castings.



2. Introduction

As the need for electricity increases, the need for environmentally friendly sources for it are also becoming more important than ever. The need to improve and optimize wind turbines is evident, as more affordable and efficient turbines will yield an overall lower cost for energy. Cast iron materials are becoming more widely used for large and complex components in mechanical engineering and drive technology. Due to the steady increase of requirements, high-strength spheroidal graphite iron is in great demand. To fully exploit the potential of these materials, an in-depth characterization of their mechanical properties is necessary. This allows for reduced safety margins.

The use of simulation tools makes the prediction of the mechanical properties and processes of casting possible to foundry and design engineers. The 3D-models of the simulation can be reviewed from all angles and sections of which the mechanical properties, solidification, defects, and other properties can be evaluated. This makes it easier for foundry and design engineers to evaluate the need for improvement and thus improving the quality and overall efficiency of their processes and products.

Through the use of cast simulation, castings can be optimized through localized prediction of real-life mechanical properties of thick-walled castings. With optimized mechanical design and structure, the castings can be made smaller with less material, thus making them lighter and more affordable.

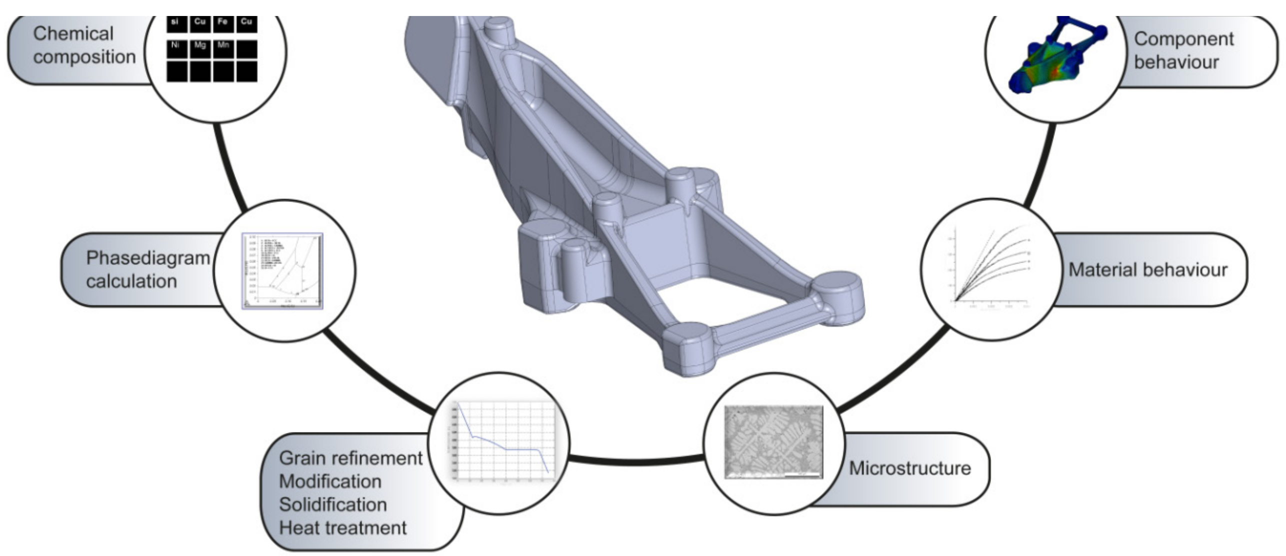


Figure 1 Olofsson, J., Svensson, I.L., 2012. Incorporating predicted local mechanical behaviour of cast components into finite element simulations.

3. Method

Castings with 2 different sizes and in 3 different conditions were made for destructive testing. Test castings went through tensile testing (Dekra Industrial Oy), hardness testing and microstructural evaluation. Casting simulations were made with Novaflow&Solid cast simulation software by Suomivalimo Oy. Finally, the localized real-life mechanical properties of destructive testing were compared to casting simulations.

3.1 Test samples and testing

For testing, heat-treated material comparable to GJS-800-2 (EN 1563:2018) was chosen as the material used in this research. This was due to the use of GJS-800-2 in wind turbine gearboxes. Also, as-cast material with comparable properties to GJS-700-2 grade was tested as a comparison to GJS-800-2 to determine the effect of the heat-treatment to mechanical properties. To evaluate different parameters in simulation, castings with combinations of two sizes and three cast conditions, totalling to 12 different castings, were ordered from Suomivalimo Oy. The test castings were chosen to specify real-life situations as closely as possible with casting models that had been used before in material testing. Two casting models of different sizes were used:

- A-series: corresponding thicker walls; A1-A6
- B-series: corresponding thinner walls; B1-B6

The three cast conditions are as followed:

- As-cast, non-heat-treated (A2, B2, A6, B6)
- As-cast, non-heat-treated, with chills (A1, A3, B1, B3)
- Heat-treated (pearlitized), with chills (corresponding to GJS-800-2 grade) (A4, A5, B4, B5)

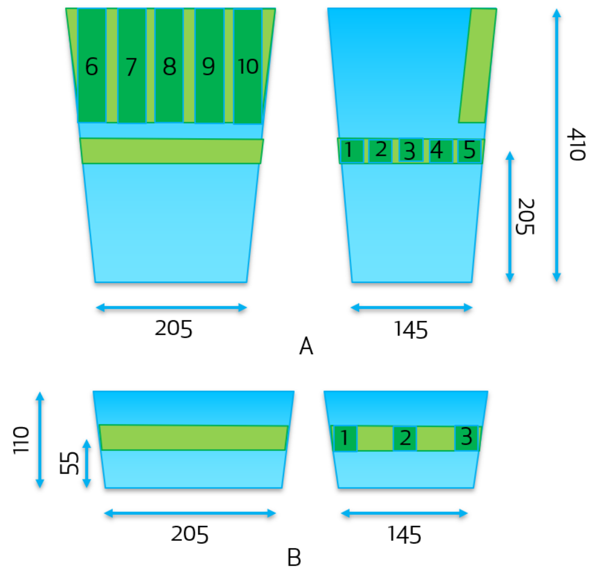


Figure 2 Initial design dimensions and test sample locations for A- and B-series castings.

The tensile testing was performed in accordance with EN ISO 6892-1:2016. For the tests, 3 samples from the smaller casting and 10 samples from the bigger casting were chosen. Test sample locations (Figure 2 and 3) were chosen based on preliminary simulation results from Suomivalimo.

Figure 3 Test castings from Suomivalimo Oy.

3.2 Simulation

A casting modulus is necessary for the simulation. The simulation software calculates the modulus automatically using the following parameters:

- The geometry of the casting
- Exothermic factors (such as the mould)
- Chills and other methods of cooling
- Thermal modulus

NovaFlow&Solid casting simulation software calculates solidification and values for hardness and UTS using set values that have been modified through experience. Simulations were made for two casting samples in two different conditions:

- As-cast, EN-GJS-700-2
- As-cast, chilled, EN-GJS-700-2

Simulations were examined locally from locations were test rods used in tensile testing were fractured to comprise accurate comparison of the real-life properties and simulation. Simulation results (Figure 4) were viewed and measured using NovaFlow&Solid Browser which was provided by NovaCast for the use of this thesis.

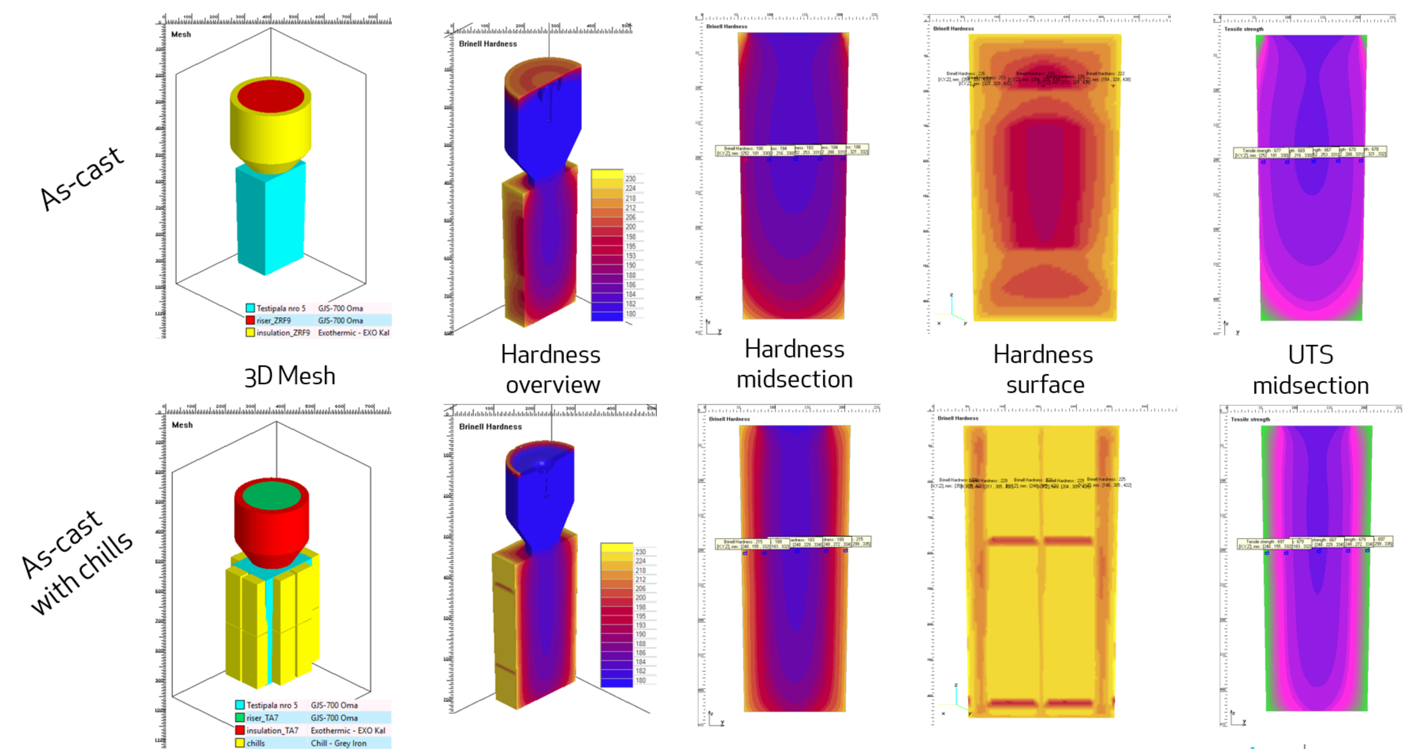


Figure 4 Overview of simulation results for A-series castings (by Suomivalimo using NovaFLow&Solid cast simulation software)

4. Results

The results of mechanical testing (tensile strength and hardness) were compared to cast simulations. Due to the inability of the cast simulation software to simulate heat-treatment, the pearlitized (GJS-800-2) samples were compared to non-heat-treated simulations. Also, the graphite morphology was evaluated using an image processing software.

Casting Series / Cast Conditions	Difference between real-life results and simulation results (positive values are the result of higher real-life values compared to simulation results)	
	Tensile Strength [MPa]	Brinell Hardness [BHN]
A-series, as-cast	0.6%	11.9%
A-series, as-cast, with chills	-11.0%	5.6%
A-series, pearlitized, with chills*	15.52%	19.2%
B-series, as-cast	-14.4%	15.4%
B-series, as-cast, with chills	2.5%	2.1%
B-series, pearlitized, with chills*	17.1%	19.5%

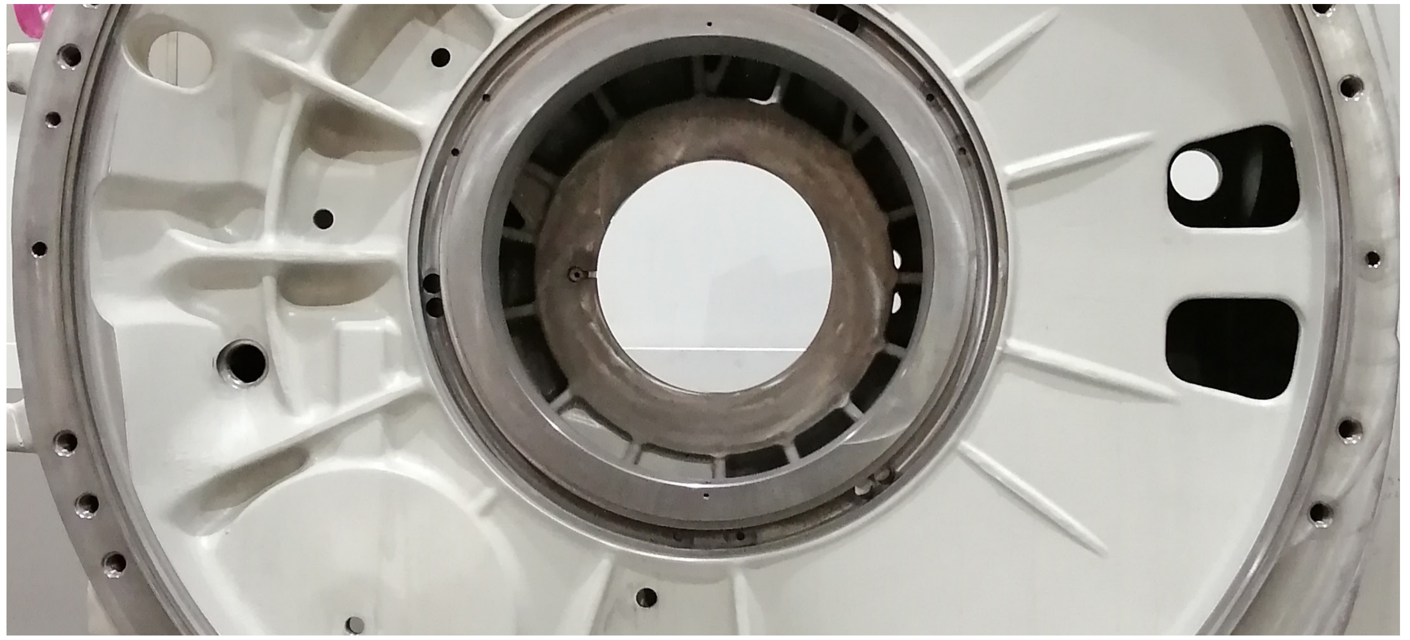
* Pearlitized mechanical testing results are compared to non-heat-treated simulations due to inability to implement heat-treatment in NovaFlow&Solid

Table 1 Summary of the differences between real-life results and simulation results.

The differences in tensile strength and hardness simulations indicate that some values are not properly set in simulation, as increase in hardness should correlate with the increase in tensile strength. Hardness values were higher in real-life than in simulations, so values could be optimized by adjusting simulation values. It was also noted that the increase in nodule count corresponds to increasing hardness, while the importance of nodule count to hardness diminishes in higher values.

5. Applications

When the method presented in this research is used to optimize high strength spheroidal graphite cast iron castings through cast simulation software, more optimized castings can be made to reduce the usage of material. Also localized mechanical values can be implemented to FEM calculation to optimize and predict local mechanical properties more accurately. Cast optimization will become more important in the future when the need to take advantage of local mechanical properties increases to lower the LCOE (levelized cost of energy) in the wind energy business.



6. Bibliography

Olofsson, J., Svensson, I.L., 2012. Incorporating predicted local mechanical behaviour of cast components into finite element simulations. Materials & Design, 34, pp. 494-500.