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EFFECT OF SOLIDIFICATION TIME ON THE MICROSTRUCTURE AND MECHANICAL PROPERTIES OF THE COMPACTED GRAPHITE IRON FOR HEAVY DUTY ENGINE BLOCK

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INTRODUCTION

- Demands for increasingly compact engines that promote lower fuel consumption, reduced emissions and increased power and torque have guided the development of engine technology for many years.

- These performance improvements, in terms of efficiency and power density (kw/l or kw/kg), result in the need for components with greater thermal and mechanical resistance.

- To meet these needs, over the years, compact graphite iron (CGI) and aluminum compete to present continuous technological innovations that promote the most attractive conditions for their selection as a component material.

INTRODUCTION

- Aluminum versus CGI:
  - Engine blocks with smaller sizes and with lower final mass in CGI than those in aluminum.
  - CGI Engines can have higher peak pressures

Aluminum
- Lower density
- Higher thermal conductivity

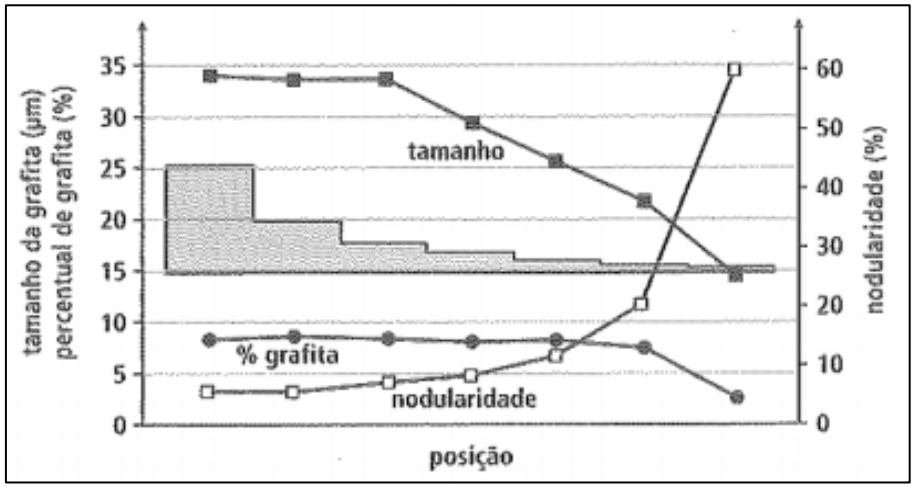
Source: Guesser (2016, p. 8)

Compacted Griphite Iron (CGI)
- Greater fatigue resistance
- Bigger stiffness
- Higher vibration dampening capacity
- Greater stable mechanical resistance in higher operation temperatures

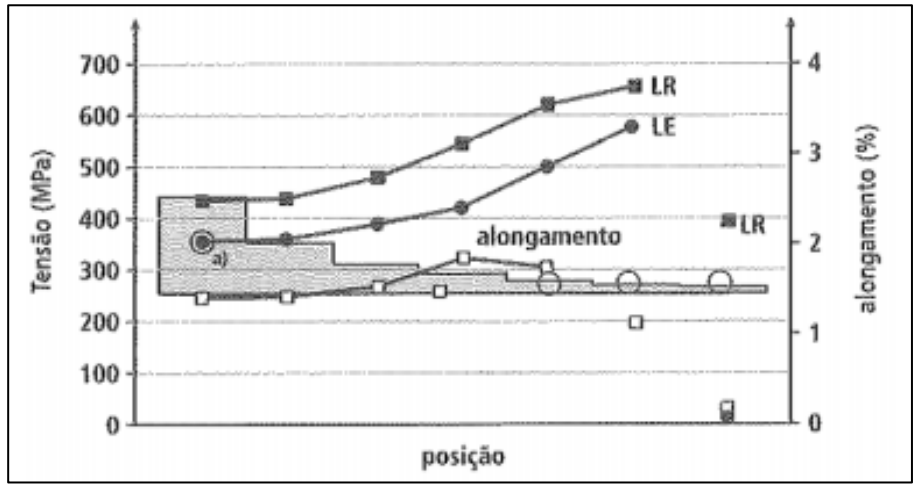
INTRODUCTION

- The microstructure of compacted graphite iron, in addition to being influenced by factors such as chemical composition, liquid treatment and heat treatment, is strongly affected by solidification time.
- So far, the available data in literature were collected in cast bars or step bars. There is a lack of data from actual components.

Source: Charoenvilaisiri & Stefanescu (2002)



Source: Scheib (2007) apud Guesser (2009, p.102)



Source: Scheib (2007) apud Guesser (2009, p.102)

INTRODUCTION

- This work presents the effect of solidification time, related to wall thickness and product geometry, on the microstructure and mechanical properties of a compacted graphite iron heavy duty engine block.

- This data base will allow designers to apply CGI in a more optimal way. It shows that is possible to reduce the component wall thickness safely, reducing the overall weight of the component.

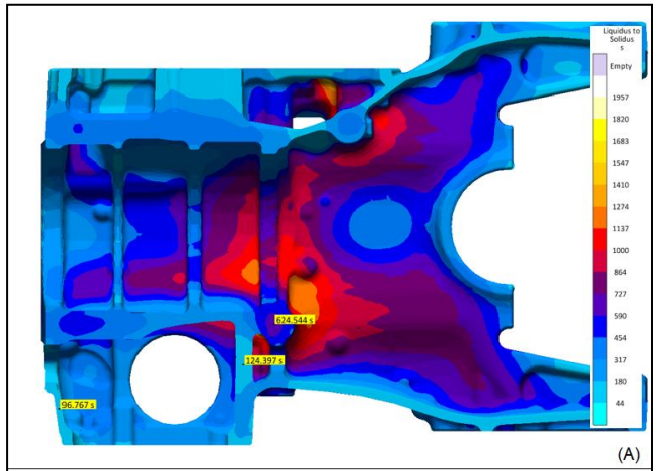
- The work presented here is part of the master thesis from one of the authors at UDESC.

EXPERIMENTAL PROCEDURES

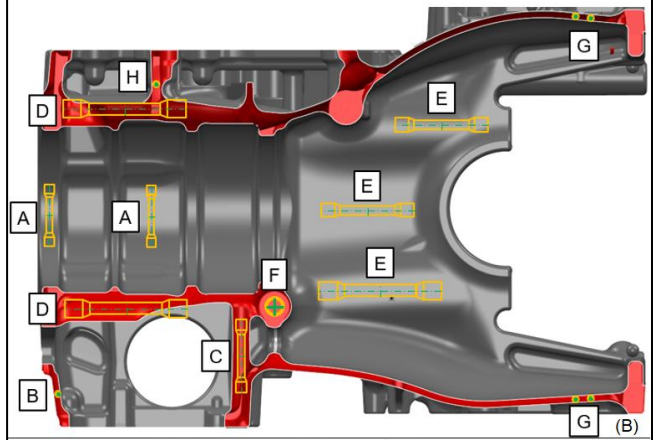
- The object of this study was a i6 300 kg engine block, casted in CGI class ISO16112/JV/400/U.

- It was select regions with section thicknesses ranging from 6 mm to 50 mm, which guarantees different solidification times. From this regions it was taken tensile and microstructure specimens for evaluation.

- The solidification process was simulated using Magmasoft® software and was used to calculate the solidification time at the different sections.



(A)



(B)

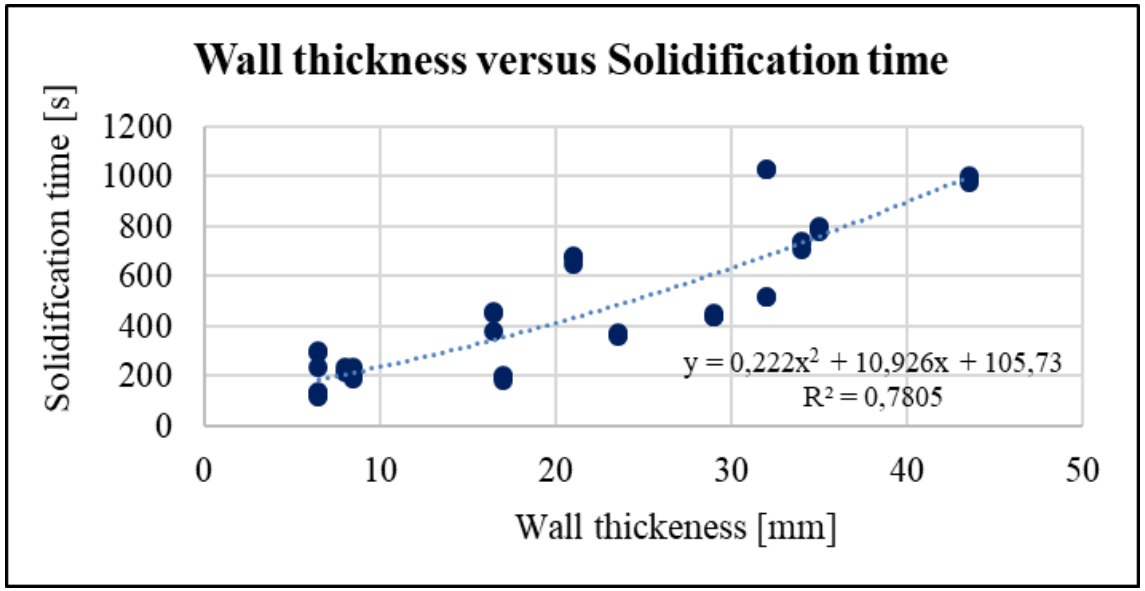
A. Between cylinders
B. Camshaft top face
C. Camshaft pin
D. Cylinder Head fixing
E. Beating
F. Oil channel
G. Pan rail
H. Water gallery rib

EXPERIMENTAL PROCEDURES

- The models to predict the effect of solidification time on mechanical properties were developed using polynomial regression analyzes of Minitab® statistical software.
- For all models, the 95% confidence interval and the 95% prediction interval were calculated.
- The reciprocal data transformation (1/x) was adopted for the solidification time data to obtain the best fits of the models.
- It was verified the extension of the developed models for parts from different cast batches.

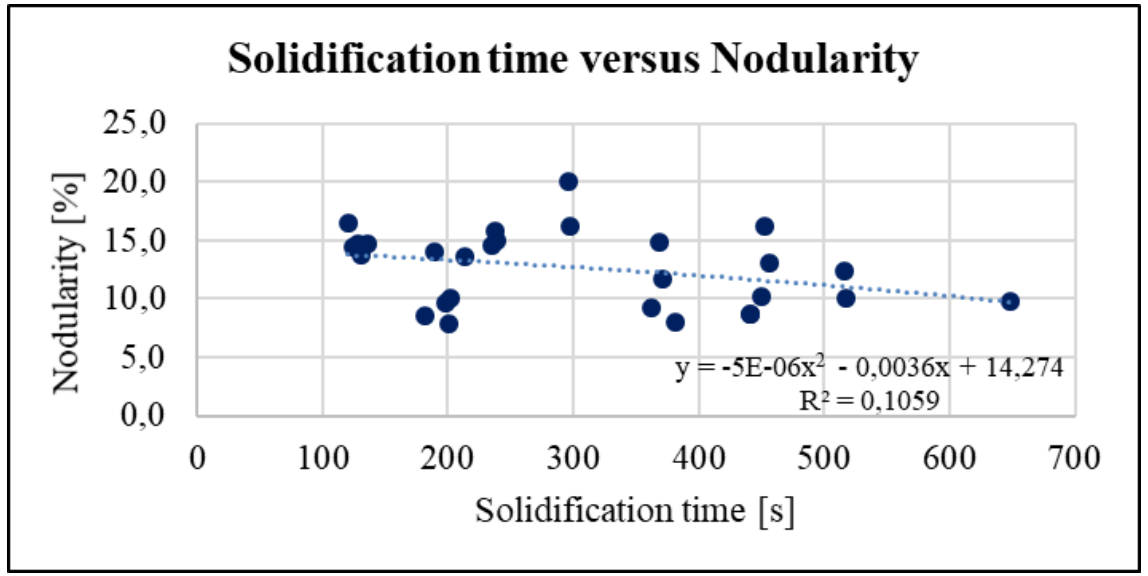
RESULTS AND DISCUSSION

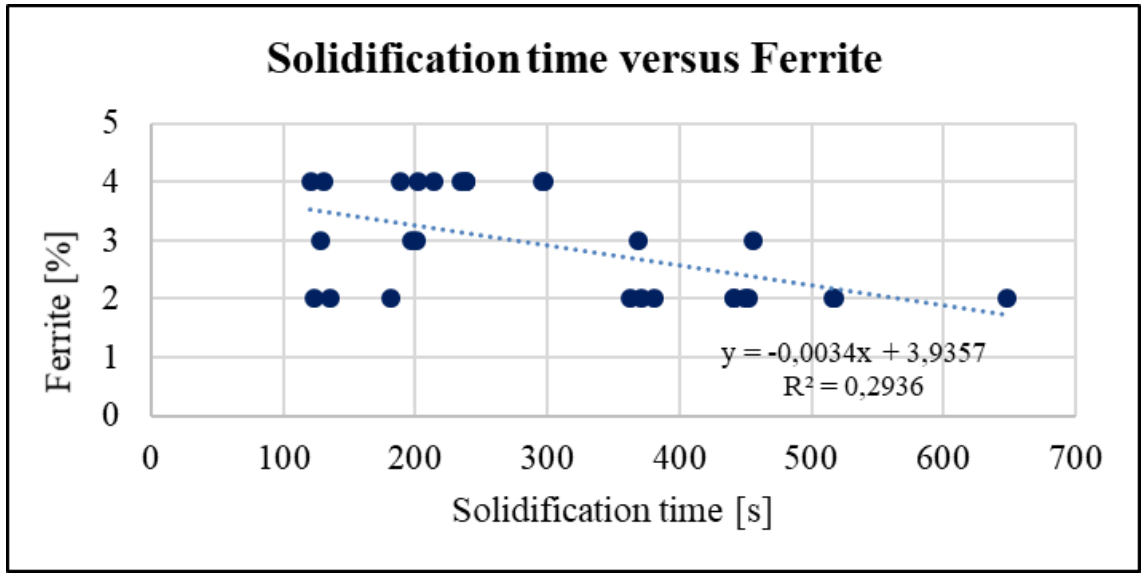
- SOLIDIFICATION SIMULATION
  - Higher cooling rates and shorter solidification times were observed in regions with thinner wall thickness.



RESULTS AND DISCUSSION

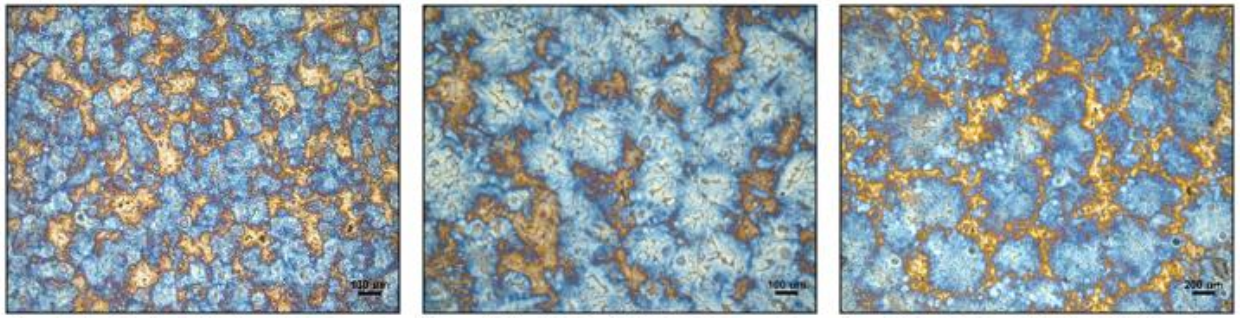
- MICROSTRUCTURE ANALYSIS:
  - **Nodularity** range was between 7 to 20%.
  - **Ferrite** content ranged from 2 to 4%;





RESULTS AND DISCUSSION

- MICROSTRUCTURE ANALYSIS:
  - The refinement of the microstructure was verified with the decrease of the solidification time.
  - There was an increase in the number of **eutectic cells** per unit of area for regions with shorter solidification times
  - A coarseness of the microstructure as the solidification time increases is evident.



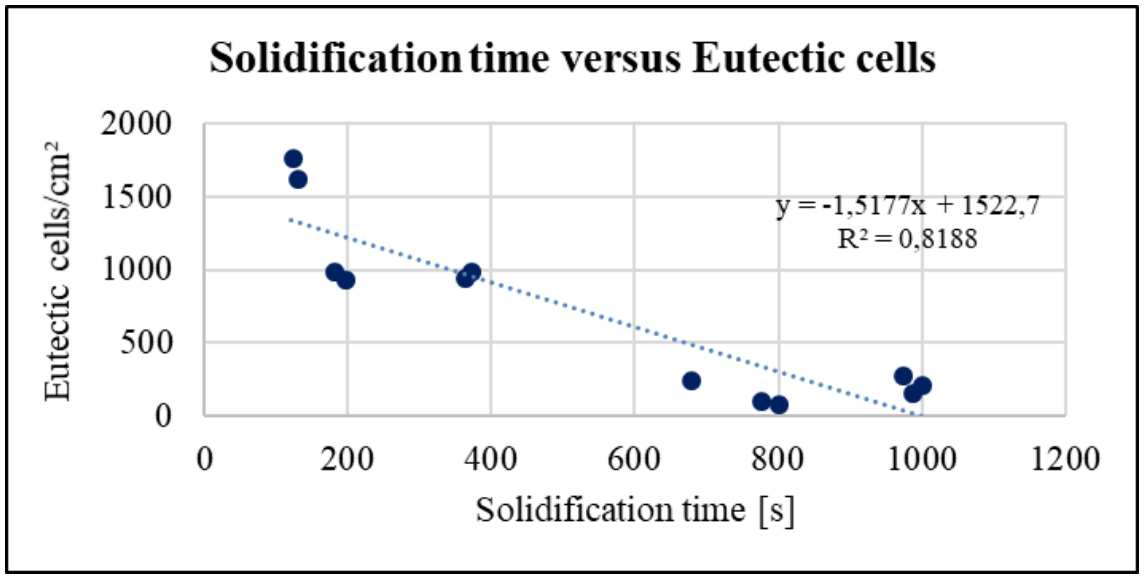
a) ST: 124s / EC: 1760/cm² b) ST: 198s / EC: 926/cm² c) ST: 363s / EC: 937/cm²

d) ST = 679s / EC: 242/cm² e) ST = 777 / EC: 105/cm² f) ST: 988s / EC: 153/cm²

Note: ST = Solidification time and EC = Eutetic cell.

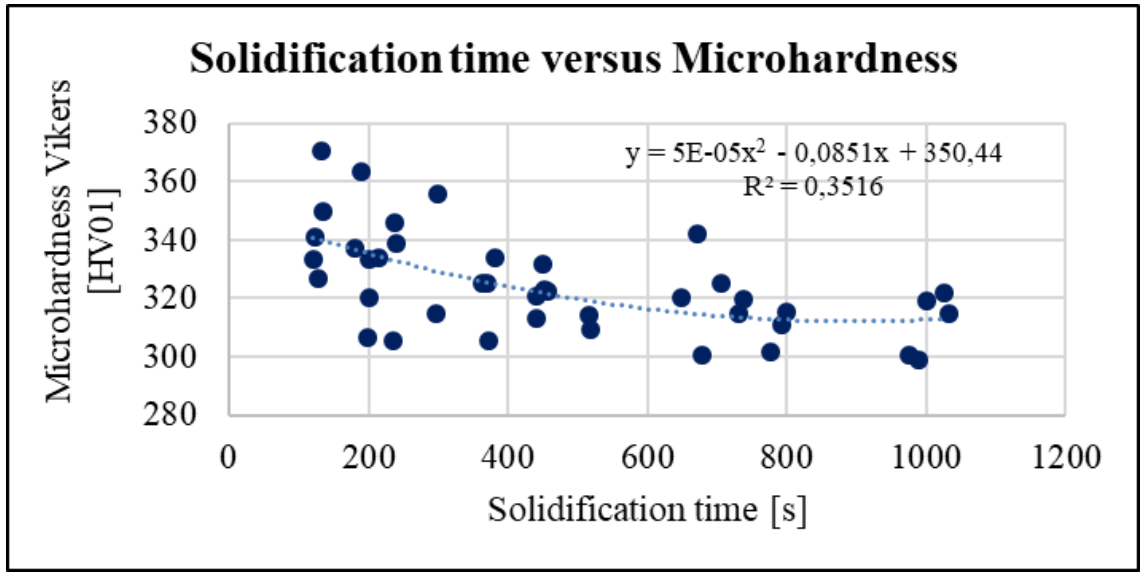
RESULTS AND DISCUSSION

- MICROSTRUCTURE ANALYSIS:
  - There was an increase of up to 10 times in the number of **eutectic cells** per square centimeter as the solidification time changes from 1000 to 180s.
  - This is explained by the high number of active nuclei in fast solidification areas and segregation profile in longer solidification areas.



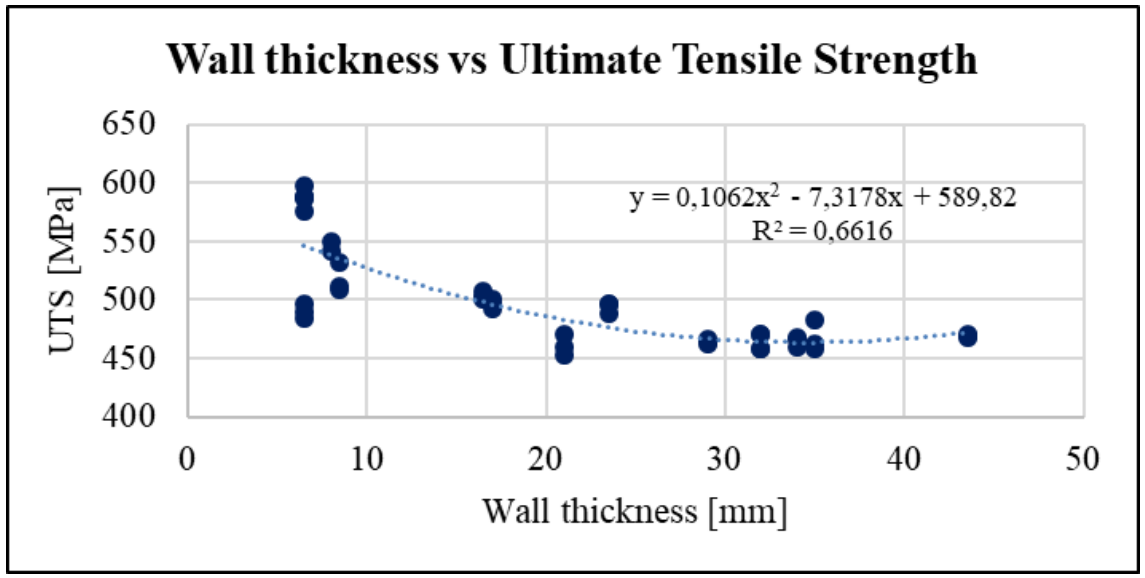
RESULTS AND DISCUSSION

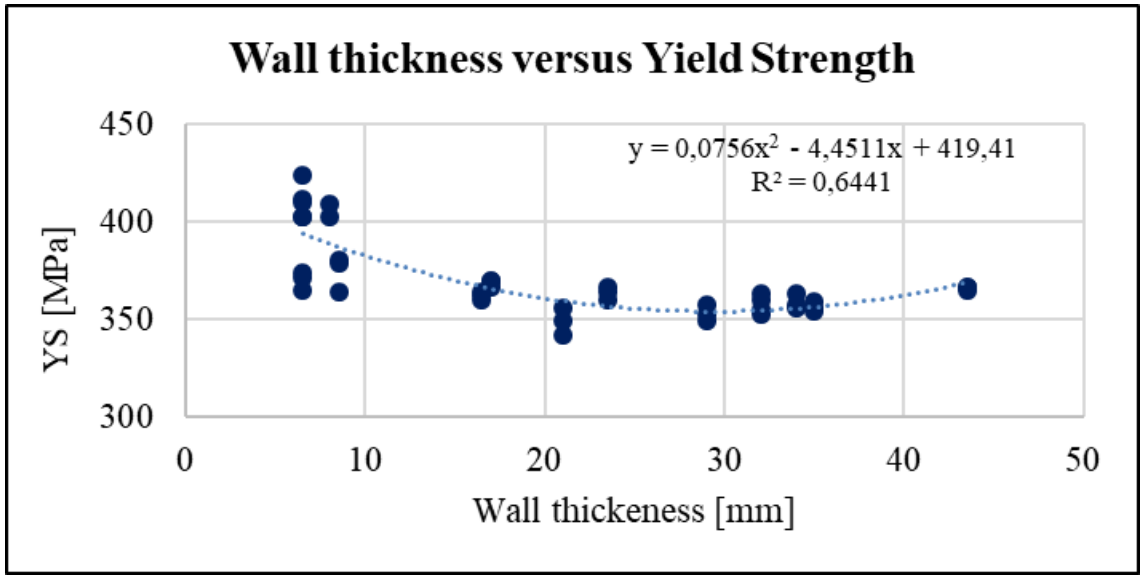
- MECHANICAL PROPERTIES:
  - **Microhardness** changed subtly, from around 340 HV in shorter solidification time sections to around 315 HV in longer solidification time sections.
  - This increase in average hardness is explained by the refinement of pearlite for the shortest solidification time.



RESULTS AND DISCUSSION

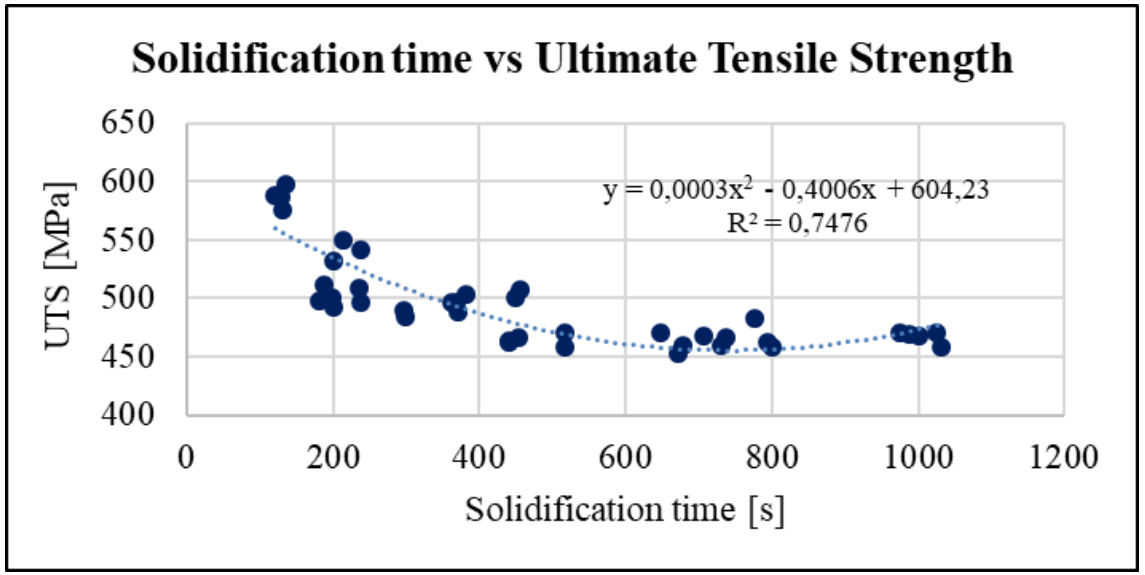
- MECHANICAL PROPERTIES –
  - A progressive increase, up to 30% in Ultimate Tensile Strength (UTS) and up to 20% in Yield Strength (YS) was verified for thicknesses smaller than twenty millimeters.

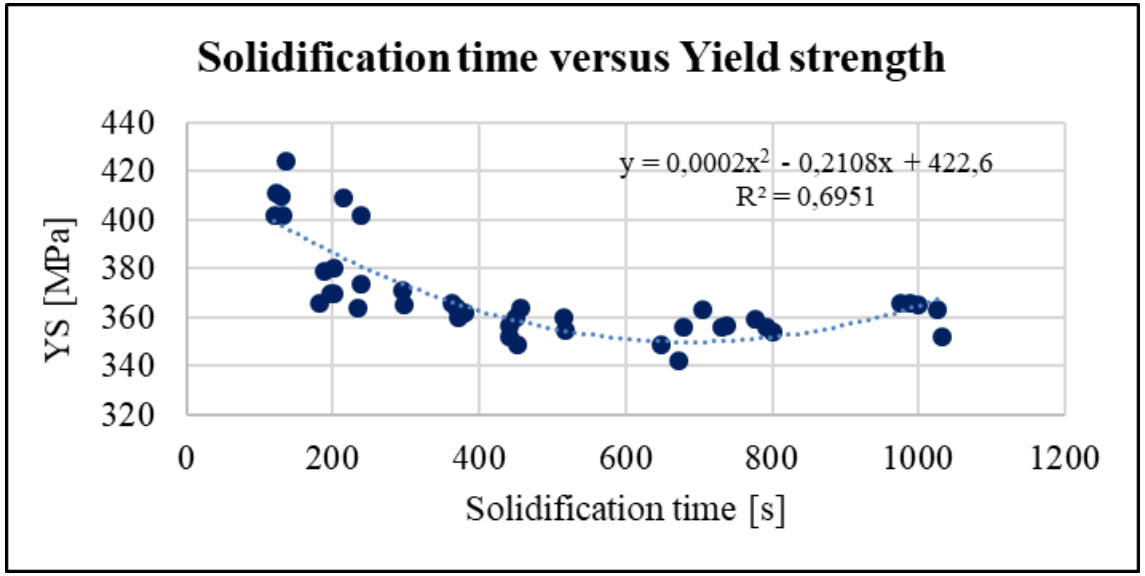




RESULTS AND DISCUSSION

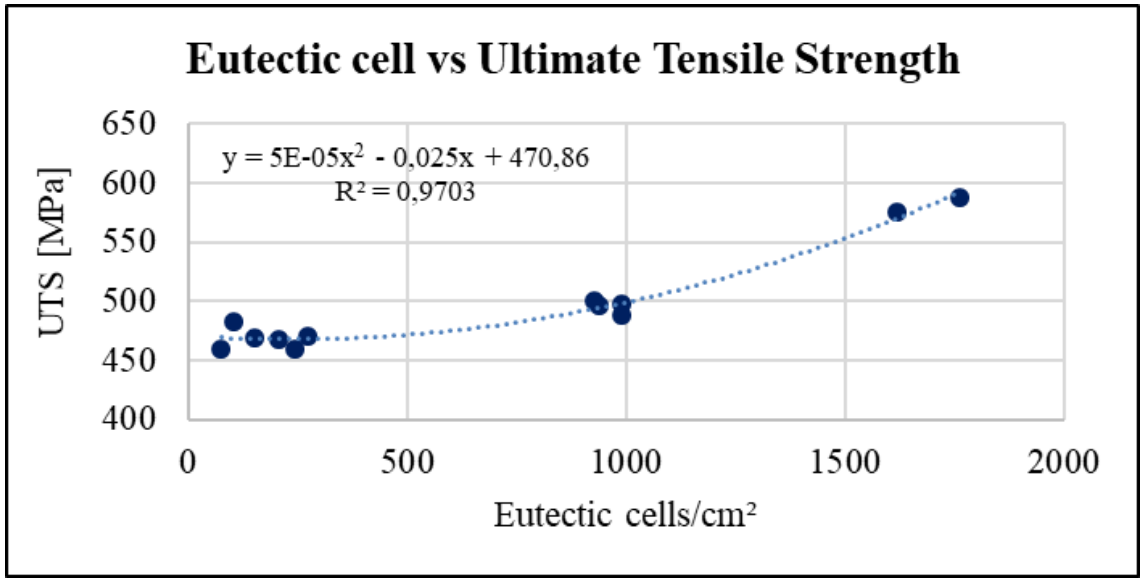
- MECHANICAL PROPERTIES –
  - There is a better accuracy of the correlation of solidification time with Ultimate Tensile Strength and Yield Strength.





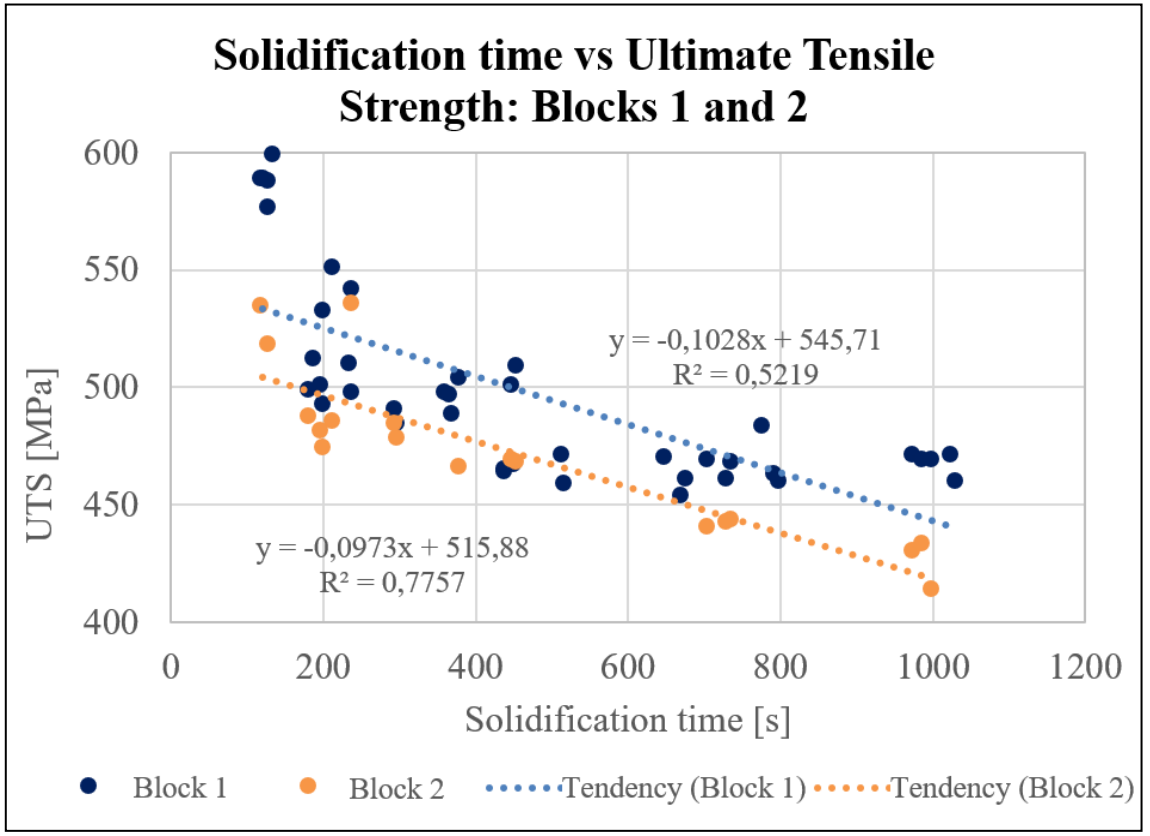
RESULTS AND DISCUSSION

- MECHANICAL PROPERTIES
  - The study showed that the microstructure parameter eutectic cell/cm² had the most significant effect on Ultimate Tensile Strength.



RESULTS AND DISCUSSION

- The behavior of tensile strength according to solidification time showed to be similar for different parts as shown by the angular coefficients.



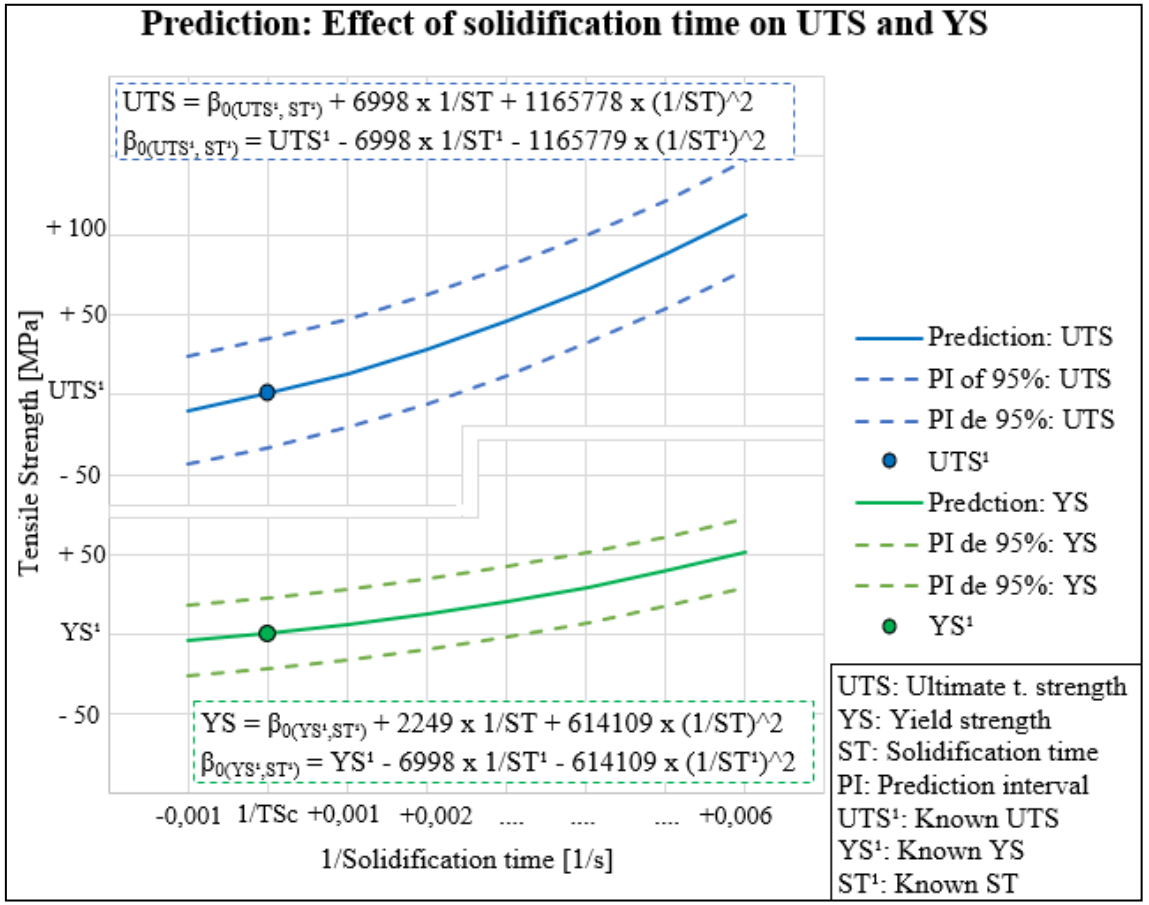
RESULTS AND DISCUSSION

- MECHANICAL PROPERTIES PREDICTION THROUGH SOLIDIFICATION TIME:

Define the constants of the equations (β_0) by inserting in the constant equations the **actual** or **desired** values of UTS and YS from a section of the part with known solidification time (ST).

⇩

Plot the curves of the equations ($UTS_{(ST)}$ and $YS_{(ST)}$) with the defined constants.



CONCLUSIONS

- There was 10 times increase in the number of eutectic cells per square centimeter with a decrease in solidification time from 1000 seconds to 150 seconds, followed by an 30% increase in UTS and 20% increase in YS.

- The increase in UTS for the shortest solidification time (100s; 7mm wall thickness) in relation to the longest solidification times (above 500s; > 30 mm wall thickness) was up to 100 MPa

CONCLUSIONS

- The increase in YS for the shortest solidification time (100s ; 7mm wall thickness) in relation to the longest solidification times (above 500s; > 30 mm wall thickness) was up to 70 Mpa.

- It was possible to predict the mechanical properties (U.T.S. and Y.S.) in different sections of the Engine Block based on the solidification time through polynomial regression models with a confidence level of 95%.

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