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# Investigation on the Production of Solution Strengthened Ductile Iron Part Grade 500-14

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**Abstract**

The aim of this study is investigating a new possibility instead of EN GJS 500-7 material. The new possibility is solution strengthened ductile iron EN GJS 500-14 with higher yield strength, higher elongation, low weight and low-cost advantages. For the selected composition, whole mechanical and microstructural properties have been achieved. The thermal analyses and the computer simulation have been studied. Results showed good correlation between experimental results and simulation. Finally, EN GJS 500-14 casting material is replaceable for 500-7 in certain conditions; tensile, hardness, elongation and yield strength requirements.

## 1 INTRODUCTION

Ductile cast iron has been used extensively in many structural applications in automotive industry due to its high tensile strength, good wear resistance, high ductility, low melting temperature and shrinkage, the highest fluidity and cost-effective way to produce components; crankshaft, camshaft, axle housings, differential carrier, wheel hub, steering bodies and suspension arms. In addition, ductile cast iron is known as a material that has mechanical properties as good as steels and has ease of manufacture of cast irons. The mechanical properties of ductile cast irons are directly related to their microstructure and in as-cast condition of matrix microstructure may be entirely ferritic, entirely pearlitic or a combination of these with spheroidal graphite in the matrix. These properties are affected by the chemical composition and the solidification–cooling rate due to the section size and molding materials. Pearlitic matrix is very hard and strength. There are two ways to obtain ferritic matrix: first one is adding 0.2% magnesium carbide alloy in chemical composition and second is annealing the material or cooling very slowly. Solidification of ferritic/pearlitic ductile cast irons starts with the precipitation of austenite in liquid phase. Matrix is austenite below the eutectic temperature and the first austenitic areas are transformed into ferrite, usually located around the graphite nodules below the eutectoid temperature. Carbon solubility of ferrite is much lower than austenite so, carbon atoms diffuse to the graphite nodules from the ferrite at a rapidly decreasing rate due to the increasing distance. Pearlite nucleates and grows rapidly because of the shorter diffusion distance between ferrite and cementite ($Fe_3C$). Thus, the remaining matrix will be pearlitic. The result is “bulls eye” microstructure, where graphite nodules are surrounded by a ring of ferrite in a matrix of pearlite. [1-6]

Meeting the demands that designers and manufacturing engineers make of a component is a special challenge for the caster. Increased strength and breaking elongation enable the designer to ensure a light component with high functionality. However, as a rule, these material properties suffer from poorer or more complicated machinability and often increase manufacturing costs substantially. Due to cost constraints, the automobile industry has been implementing solutions that mark a turn toward modified materials for a long time now. [1] The silicon solution-strengthened ferritic ductile cast iron has recently become widely used as a structural material [2], and its tensile strength has been specified as being up to 450–600 MPa in ISO1083 and EN1563:2011. By increasing the silicon content of 3.0–4.3% solution-strengthened ferritic ductile cast iron, the as-cast matrix structure is a single ferrite phase and the tensile strength is increased to 450–600 MPa by silicon solid-solution strengthening. When the silicon concentration is high, the eutectoid transformation temperature becomes higher, and, when there is a ferrite single phase, as the diffusion of carbon from graphite to the matrix structure rate limits the austenization process [3], it is thought that the range of transformation due to weld heat becomes smaller compared to conventional ferrite–pearlite type ductile cast iron.

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## 2 EXPERIMENTAL PROCEDURE

For this study, a bearing part and a steering body part has been selected for weight reduction reasons. (figure 1) A Y shaped test block also added on the casting system of steering body in order to determine material properties in homogenous wall thickness conditions. The casting systems both for two parts prepared in 3D software for simulation study. The materials which are defining to simulation are mostly same molding materials with exception of alloy composition. The chemical analyses of alloy have been selected from literature that will mentioned afterwards of this text. [1-4]

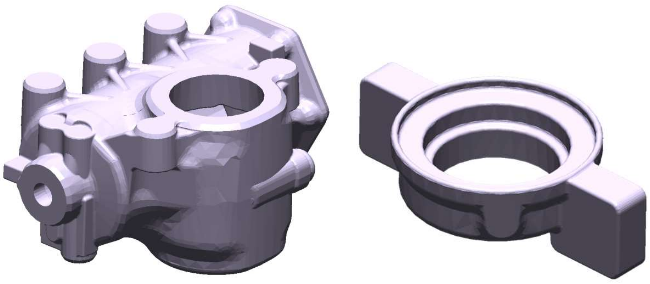

**Figure 1.** The selected two parts; steering body and bearing

The framework of this study, alloys were produced in an 8000 kg induction furnace (medium frequency). The basic analysis of the alloy was C: (3.1-3.2)%; Si: (2.3-2.4)%; Mn: (0.15-0.20)%; P: <0.020%; S: <0.009%; Mg: (0.040-0.050)%. During tundish cover treatment with FeSiMg, the pre-alloy was covered by small cut sheets from steel. The tapping temperature was from the induction furnace was set at (1520-1540)°C, the casting temperature was between 1440°C and 1450°C. Inoculation took place in the pouring basin by in stream inoculation during pouring. The melt was prepared the same basic charge 40% steel and 60% pig iron.

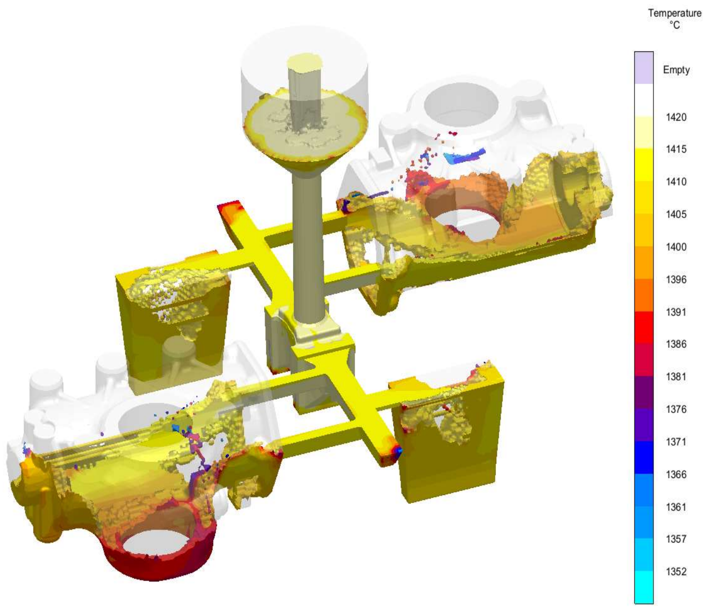


**Figure 2.** The casting system of Steering Body with standard Y shaped blocks.

While the pouring of molds near the sampling area of pouring robot, a thermal analyses setup has been created by using a computer, a data logger and a Quick Cup © without Tellurium. The same % of instream inoculant has been added at the bottom of cup and 400 gr of magnesium treated melt has been poured to the cup from the same pouring ladle of test casting moulds. Also, the spectrometer results confirmed that the chemical analyses were same with the melt in mould and test cup. The time and temperature data have been collected by data logger with 100ms time period and saved with computer for further thermal analyses. The phase transition temperatures determined and defined in simulation from the cooling curve shown at figure 3.

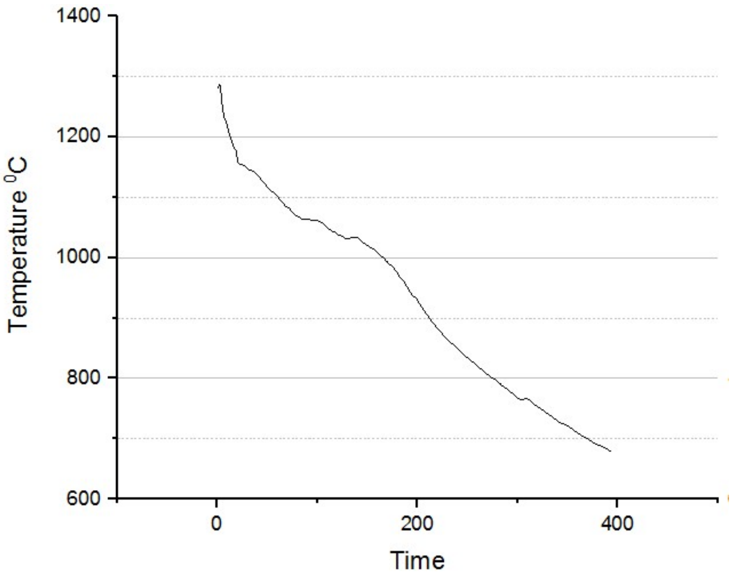


**Figure 3.** The cooling curve

## 3 THE CASTING & SIMULATION RESULTS

After the pouring, the shakeout time is 100 minutes in cooling tunnel. That means while the mold was passing through the cooling tunnel, the casting system was cooling down in mold (slow) condition. Then the final shot blasting and fettling operations has been applied on casting after the removal of casting system components; runners, gates, feeders and pouring basin. All examinations have been made, on materials from casting and test blocks separately cast but poured together in same casting system, as cast conditions. No heat treatment procedures were carried out. The figure 4 shows the tensile test specimen location on steering body and standard Y shaped block.

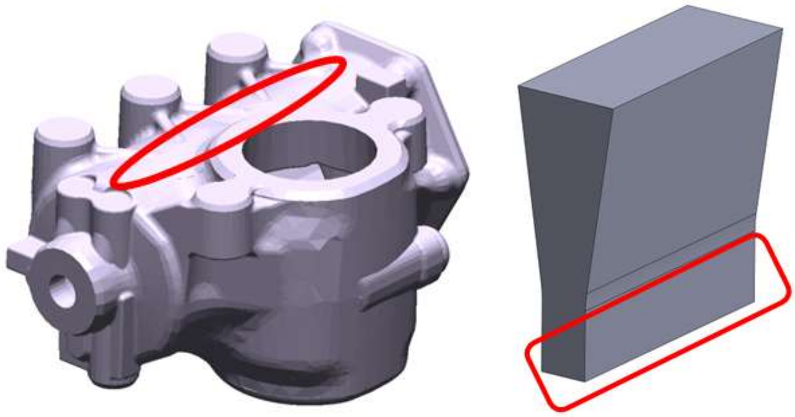

**Figure 4**. The tensile test specimen locations from steering body part & Y shaped block

The tensile test results have been listed on table 1. below. The sample #1, #2 have been taken from body part and the sample #3, #4 have been taken from Y shaped block and machined and tested according to EN 1563:2012 standards. The results showed that the poured materials met the mechanical requirements of standard. In EN 1563:2012; the 0.2% proof strength(yield) has to be min. 400 MPa, the tensile has to be min. 500 MPa and the % elongation has to be min. 14% according to relevant wall thickness which is smaller than 30 mm. (Fig. 5a)

**Table 1.** Mechanical Test Results

| Samples | Yield Strength MPa | Tensile Strength MPa | % Elongation |
|---|---|---|---|
| **#1(part)** | 456.61 | 548.80 | 15.40 |
| **#2(part)** | 462.15 | 558.42 | 16.10 |
| **#3(block)** | 470.20 | 565.60 | 17.80 |
| **#4(block)** | 472.10 | 568.20 | 18.10 |

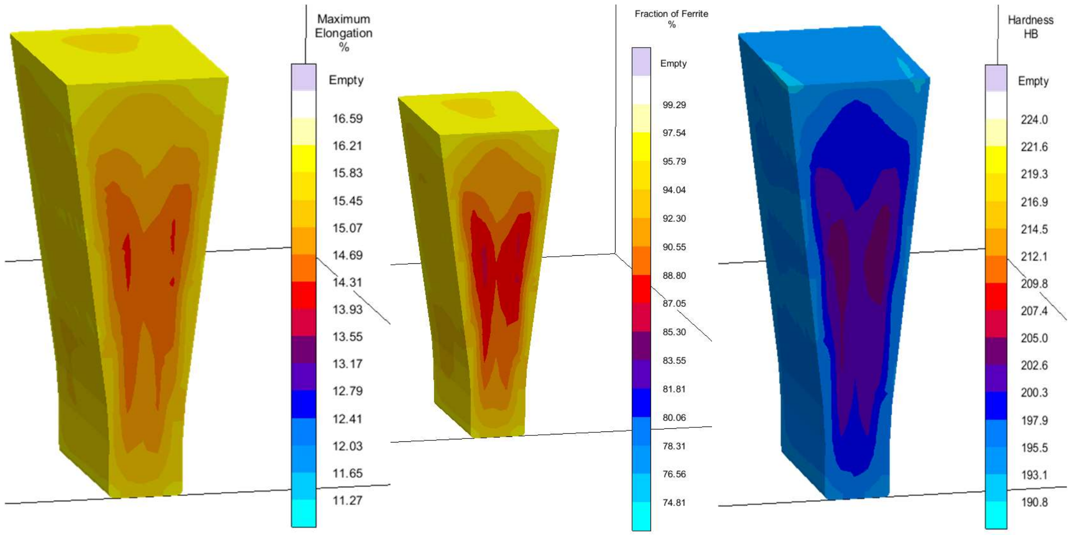


**Figure 5.** The maximum elongation, Fraction of Ferrite results for Y shaped test block and Hardness

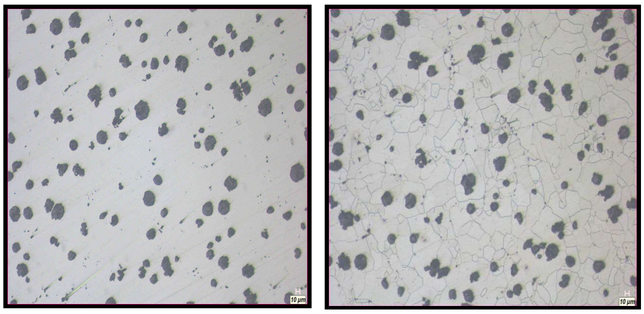

**Figure 6.** Un-etched and etched micrographs from tensile test specimen section of Y shaped test block

The figure 5b and 6 shows that there is also good correlation between simulation results and real casting micrographs. The relatively low nodule counts due to low carbon content and fully ferritic microstructure. The microstructure is form VI 6-7 graphite with 90% nodularity 175 nodules/inch$^2$. The average hardness is 200-205 HB hardness. (Figure c)

## 4 RESULTS & DISCUSSION

When compared to BS EN 1563:2011 standard [5], EN GJS 500-4 material has 290-320 MPa 0.2% Proof strength according to wall thickness, 420-500 MPa tensile strength, 5-7% elongation and 150-230 HB hardness depend on wall thickness. The EN GJS 500-14 material has achieved 390-400 MPa %0.2 Proof strength, 480-500 MPa tensile strength, and 12-14% elongation and 170-215 HB hardness depend on wall thickness. That means when we achieve EN GJS 500-14 material mechanical properties with microstructural requirements like the nodularity, the nodule count and nodule shape, in certain conditions it's replaceable to more widely used standard material EN GJS 500-7.

The advantages of EN GJS 500-14 for EN GJS 500-7 are; low density about 1.5% and the load carrying section could be decreased by comparing the 0.2% Proof strength (average 305/490=0.745 times) which provides low weight opportunities. The absence of perlite provider elements as Cu, Sn and lower amounts of Mn provides cost reduction (about 5%) in melt shop. By the elongation with 14% (two times of 7% for EN GJS 500-7) it can absorb more energy till rupture. (The fracture toughness is 72 while the EN GJS 500-7 has 63) The more homogenous hardness distribution (independence from section thickness) provides good machinability and increases tool life.

## 5 ACKNOWLEDGEMENTS

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