PRODUCTION AND ASSESMENT OF COMPACTED GRAPHITE IRON DIESEL ENGINE BLOCKS

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ABSTRACT

Diesel engine blocks properties such as tensile strenght, heat conductivity, sound damping, engine vibration and noise are strongly influenced by graphite shape and volume percent in the matrix microstructure.The shape and volume percent of the graphite particles are characterized by image analize systems. In this study, the engine blocks were produced at ELBA Basınçlı Döküm Odöksan Cast iron foundry in Osmaneli Turkey by furan resin sand and liquid alloy were treated with Mg by using ladle method. The main purpose of this study is to achive %20 -25 volume nodularity and remaining is compacted graphite in the produced engine blocks.

Keywords: Compacted graphite iron, engine block, Mg:S ratio, solidification simulation

INTRODUCTION

In general grey iron have higher thermal conduction, better tribological properties and lower mechanical strength compare to spherodical graphite iron. There is a need to create a cast iron having properties in between grey and ductile iron which aims at almost as high thermal conduction and tribological properties as the grey ones but at the same time a relatively high mechanical strength in proportion to the ductile irons. So, in the last four decades compacted graphite iron (CGI), which also called vermicular iron, has been developed. [1] It is point out that the development of the diesel engine technology has been driven by emissions legislation and the demand for higher performance from smaller engines together. The advent of common rail and unit injector ful management and delivery systems, which allow for higher cylinder pressures in direct diesel engines is among one of the most important of these developments. More efficient combustion, improved performance, reduced emissions and quiter engine operation are provided by the higher peak firing pressures. On the other hand, the increased firing pressures are said to place increased mechanical loads on the main bearing region of the cylinder block, potentially resulting in premature fatigue failures. Therefore, the irreversible trend toward higher peak firing pressures have made engine designers to find stronger materials so as to meet durability targets without increasing the size or weight of their engines. [2,3,4,5] In order to obtain these properties which is said before in the document nodularity % should be 0 to 25%. Nodularity values which is above 25% leads to increase in UTS, elastic modulus and fatigue strength. For these reason the basic objective of this study is to obtain the nodularity rate between 0 - 25% in engine blocks which we have produced and will produce. The benefits of getting nodularity rates between 0 – 25% were included in the documents presented before. To achive these objectives, especially to get desired compated graphite structure, evaluating the effect of carbon, Si, Al, S, Cu, Sn, P, in particular the optimum values of Mg/S ratio were studied. The degrees of optimum values of Cu and Sn must be evaluated to obtain 90% perlite in the alloy matrix. In addition to this, % nodularity change must be investigated according to design and the section thickness of the engine blocks. Besides, the amount of innoculant and the type of it must be optimized. According to studies we can say easily that cooling rate is as important as chemical compositions. Therefore CGI diesel engine blocks flow and solidification were studied by Novacast Novaflow simulation program. Simulation results and experimental results of com graphite

Some tests were also done such as ultrasonic test is one of them. This test is used for obtaining nodularity values without cutting the CGI diesel engine blocks. As opposed to grey and ductile irons, foundries are prevented by the sensivity of CGI to magnesium and inoculant additions from adopting the traditionally conservative philosophy of overtreatment. The meaning of sensivity of CGI to both magnesium and inoculant is that CGI is stable within a four-sided window and not on a simple magnesium plateau. Figure.5. As a consequence, reliable CGI production requires simultaneous control of the magnesium and inoculant from the start until the end of casting in order to stay within the microstructure specification [3] However in this study we obtained the best results (high compacted graphite rate) without inoculant addition because inoculant addition leads to increase in nuclei into molten iron and nuclei results in increasing nodularity values. As a consequence, inoculant addition increase nodularity values in most thin sections in diesel engine blocks.

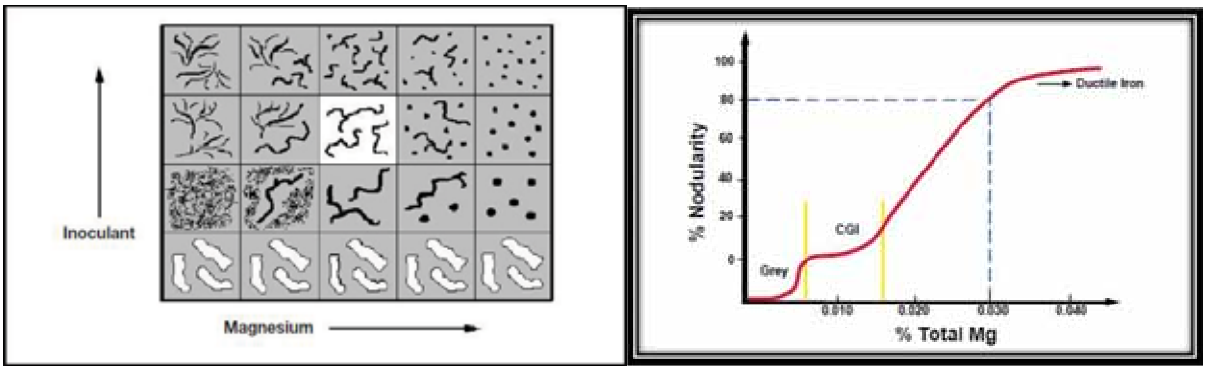


Figure. 1. a) Change of graphite shape to both Mg and inoculant can be shown within four sided window b) The proposed CGI range to achieve minimum % spheroidal graphite.[3]

EXPERIMENTAL

A number of SG iron castings were used at industrial scale at ODÖKSAN Foundry in coreless induction furnaces and after ladle treatment liquid cast iron was poured in furane resin moulds as final engine blocks. Special Mg and Ce containing inoculants were used in the pocket of the ladle to recover Mg. In order to avoid nodular graphite formation at thin sections and to increase compacted graphite formation FeSi post inoculation was not used. After we cut and obtained samples from different thickness of engine blocks, the samples were polished with a series of abrasive papers and etched in Nital; afterwards they were examined under optical microscope, Soif XJP-6A. The nodularity values were obtained with the help of Materials Plus image analyzer systems. Furthermore, ultrasonic test was done by using USM 35 flaw detector test machine.

RESULTS

After samples had been cut form different sections of the blocks, they were examined by using optical metallography and an image analysis program. The results are given in Table 1. It gives the chemical compositions of some compacted graphite iron diesel engine blocks which were tried in this project. So as to produce compacted graphite diesel engine blocks, the chemical composition is the most important part. Figure 1 shows the microstructural characteristics of the diesel engine blocks produced at Odöksan by furan resist sand, ladle method, which includes basically compacted graphite and sphero graphite irons. Thus, the composition of alloys which are produced are adjusted according to the microstructure requirement containing %20 Vol compacted graphite in the matrix and the values are shown in Table 1.

Table 1. Chemical composition of compacted graphite iron diesel engine blocks produced in this study.

Casting	C	Si	S	P	Mn	Cu	Sn	Mg	CE
P1(D10 p4-1)	3.73	2.05	0.021	0.063	0.22	0.57	0.012	0.017	4.41
P2(D8-p1-1)	3.80	2.12	0.017	0.040	0.21	0.03	0.08	0.018	4.50
P3(D8-p3-1)	3.65	2.08	0.013	0.040	0.19	0.03	0.007	0.015	4.34
P4(D10-p1-1)	3.64	1.96	0.02	0.06	0.20	0.42	0.010	0.013	4.29

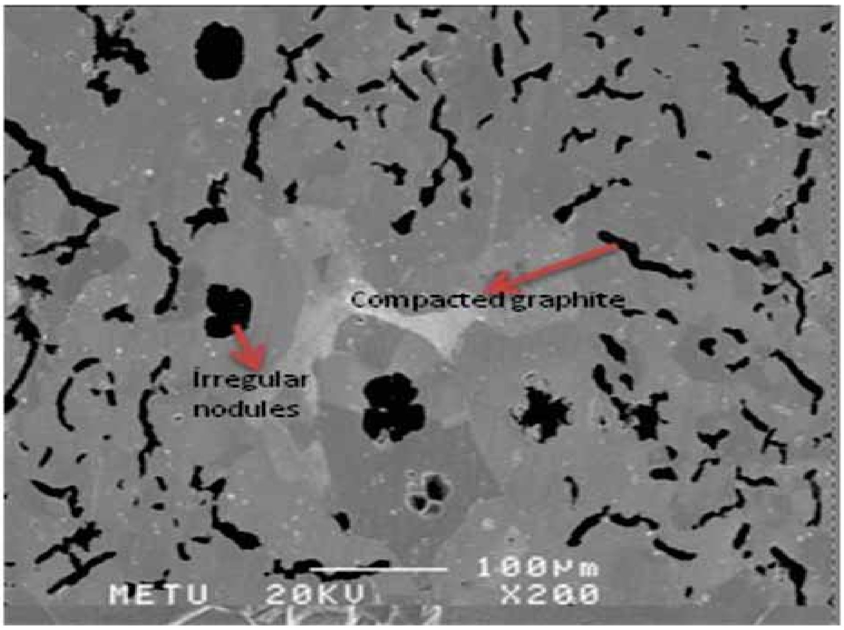


Figure.2. Compacted and sphero graphites are shown on the sample, which has the thickness of 36,26 mm.

Formation of flake graphite is not recommended, for presence of even a small amount of flake graphite leads a reduction in tensile strength and elastic modulus.

44 diesel engine blocks were produced at Odöksan by using resin sand casting methods in this study and each one is approximately 125 kg in weight. 14 different points with different section thickness are given in Table 2 and marked on the diesel engine blocks.

Samples	Average thickness (mm)
No 1	32.72
No 2	36.26
No 3	35.86
No 4	9.82
No 5	40.85
No 6	7.99
No 7	11.08
No 8	7.25
No 9	13.94
No 10	16.30
No 11	10.95
No 12	12.71
No 13	10.39
No 14	9.48

Table 2. Specimens taken and examined form different sections of the diesel engine blocks.

In these figures (see Figures 3- 4), different thicknesses which were shown in table 2 can be seen on the diesel engine blocks simulation.

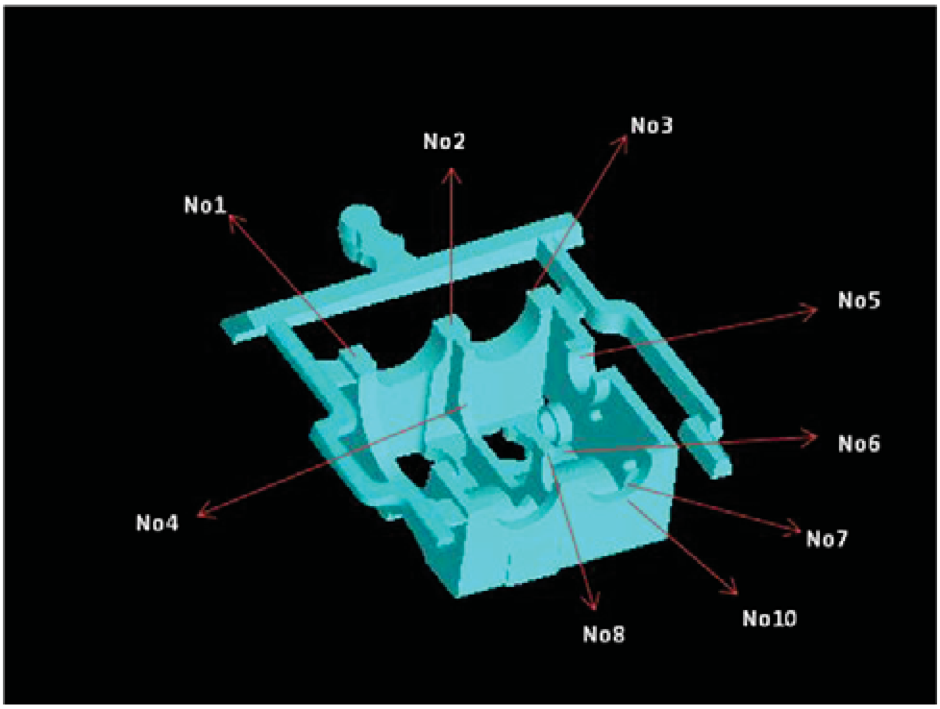


Figure. 3. First five samples and samples 6 – 7 – 8 – 9 can be seen on the above figure

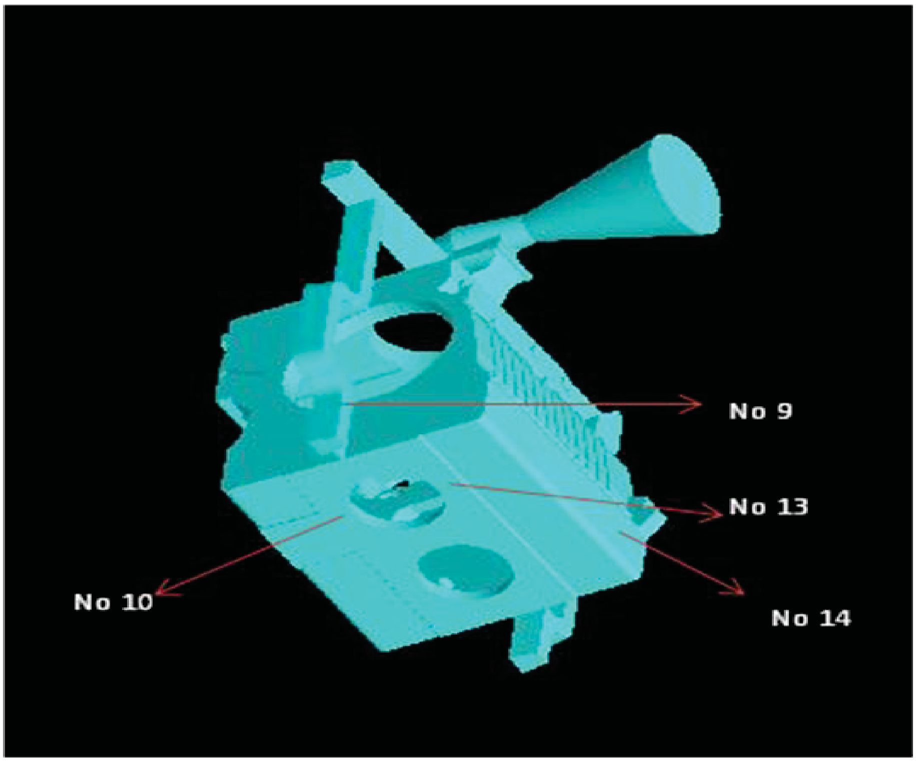
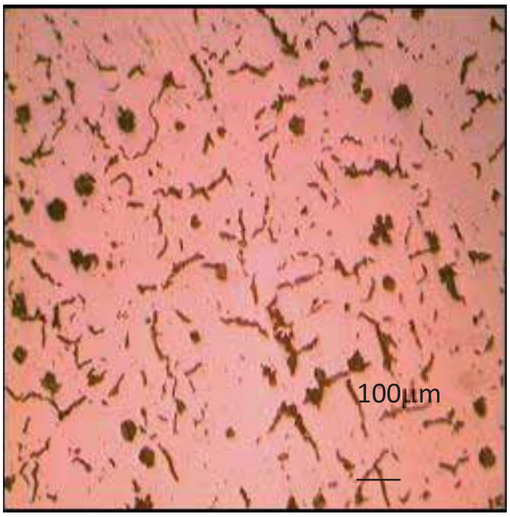


Figure. 4. Samples 9 – 10 – 13 - 14 were taken from the points marked on the figure.

Succesful CGI casting were obtained and results are presented in the following figures. In Figure 7, it can be seen that there is an example of micro structure which was taken from the sample of engine diesel engine block section with the thickness of 35.86 mm from P2 casting.



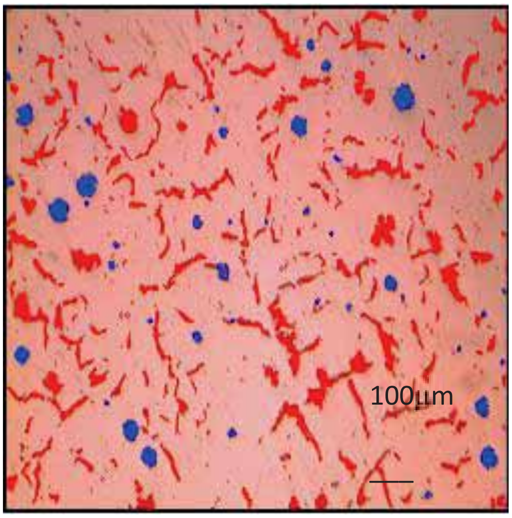


Figure5. In this figure, which was obtained from P3- No 14 casting, sphero graphites are represented with blue and compacted graphites are represented with red.

According to Table 1, % Mg values of P1 – P2 castings are in the optimum range given in the Figure 1. They yield higher compacted graphite iron percentage when compared to P3 – P4 castings, for CGI is stable within a very narrow Mg concentration ranging from 0.013 to 0.017. [4]. For this reason, initial base treated iron of P1 – P2 is not very close abrubt CGI/ grey iron microstructural transition condition given in Figure 1. These castings contain more CGI than P3 – P4 castings as P3 and P4 have lower CE values in the range of 4.2-4.3 and lower Mg contents in the range of 0.013-0.015.

For metallographic investigation, engine blocks were cut to obtain samples from points with different thicknesses. In order to evaluate and correlate the compacted graphite percentage with the cooling and filling conditions, solidification and flow simulations that were performed by the Novacast Novaflow code were used.

In comformity with the articles, it was observed that the nodularity values decreased with the increase in thickness of engine blocks due to the decrease in cooling rate. On the other hand, some points may not conform with this condition. The reason why it occurs can be explained as the cooling of liquid metal during filling in the mold cavity. Indeed, CGI is only stable in a very narrow process window. Hence enough CGI structure does not exist in these sections owing to high cooling rates.

The samples were obtained from P3 castings, and simulation results were compared with the % nodularity values obtained by image analysis. The section No 5 is the thickest part of the diesel engine block with the thickness of 40.85 mm which contains 26.79 % nodularity. Even so the section No 1 with 32.72mm thickness, which is lower than No 5' nodularity % values, possesses a nodularity % between 18 – 22 in the section of diesel engine blocks. This is an unexpected result because nodularity increases with decreasing section thickness in the step block test specimens. It can be explained that filling sequence and cooling of the liquid metal rising in the casting cavity alter the solidification conditions resulting in the formation of spheroidal graphite at some thick sections.

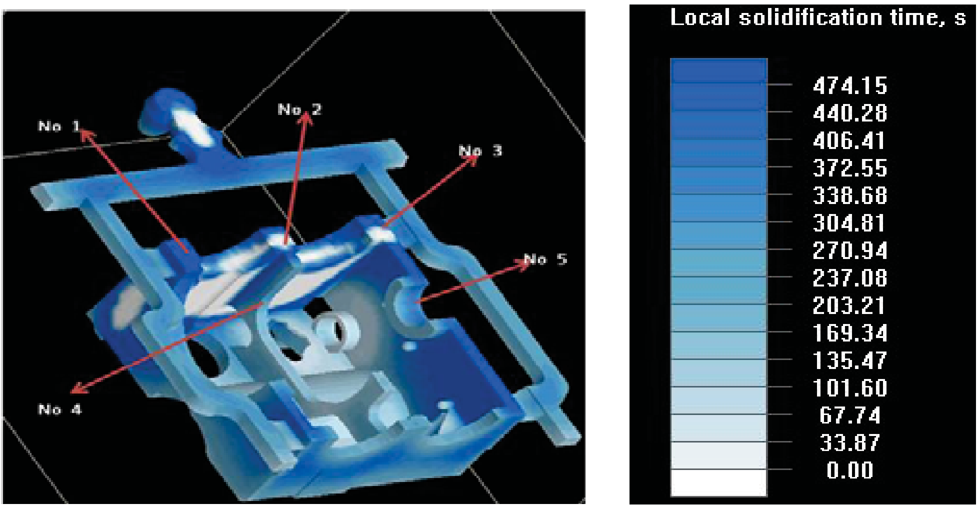


Figure. 6. Shows simulation of solidification and local solidification time values of the engine block

As the simulation results are considered, it can be realised that No 1 has the slowest cooling condition. Even though No 5 has 30 % nodularity value, a thickness value of 40.85 mm and local solidification time as 300 seconds, No 1 has 23 % nodularity values with 32,72 mm thickness and 470 seconds of solidification time.

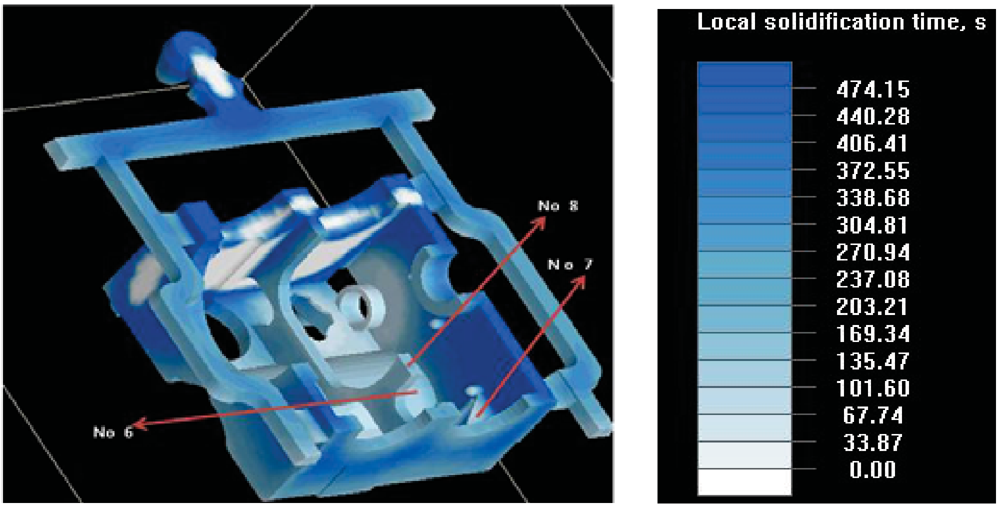


Figure. 7. Because of the reason that No 8(40 sec) and No 6(30 sec) are the points that cooled before other points such as No 7(220 sec) of the diesel engine blocks, nodularity values should be lower compared to all others of the diesel engine parts. Besides, there can also occur unexpected values. For instance, No 7 has a triangular shape and although it is a thin section with 11 mm thickness, it has 21.62 % nodularity.

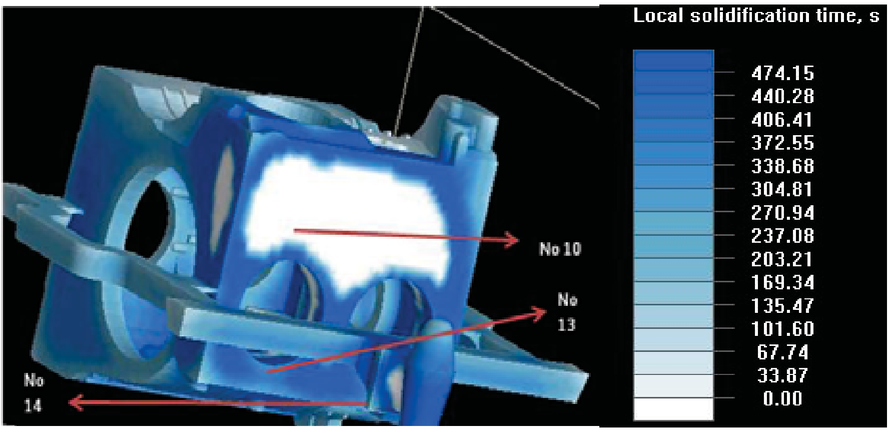


Figure. 8. In this figure it can be seen that the section point of No 10 (Local Solidification time:20-25 seconds) with the thickness of 16.30 mm has a nodularity value of 33.22 % which is a higher value compared to the other two points No 13 and 14. However, this is not the case that happens all the time; in other words, there also exist some castings in which, section points No 10, No 13 and 14 have nodularity % values that are too close to each other.

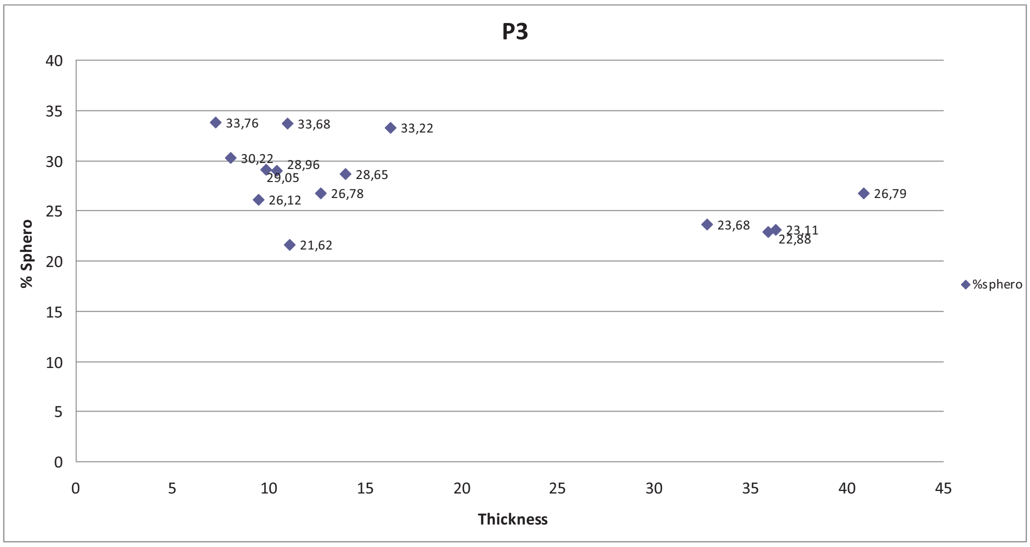


Figure. 9. In this figure, nodularity % values against section thickness obtained by using image analyze systems for casting P3 are presented

The main reason why this study was conducted is to examine the values of diesel engine blocks produced - % nodularity without cutting the engine blocks. As a consequence, engine blocks might be used after testing.

Diesel engine blocks belonging to sample casting 7 were tested by using USM 35 flow dedector test machine at METU. In order to determine the percentage of the different CGI obtained, ultrasonic tests were done on 4 different diesel engine blocks without cutting and obtaining the samples, on the points shown on table 1, figure 3 and 4. % nodularity values in the thickness of sample casting 7 were obtained before.

Using the values on the table , tha table of ultrasonic velocity- % nodularity was obtained.

Ultrasonic test results which were obtained from experiment 7 are shown below.

Table 3. These values are taken from six different diesel engine blocks by being examined

Casting No :	Thickness (mm)	Average sound velocity (m/s)
1/1	27,1	5332
1/2	27,8	5284
2/1	29,7	5327
2/2	26,9	5216
3/1	28,4	5026
3/2	28,5	5018
4/1	27,2	5305
4/2	28,1	5200

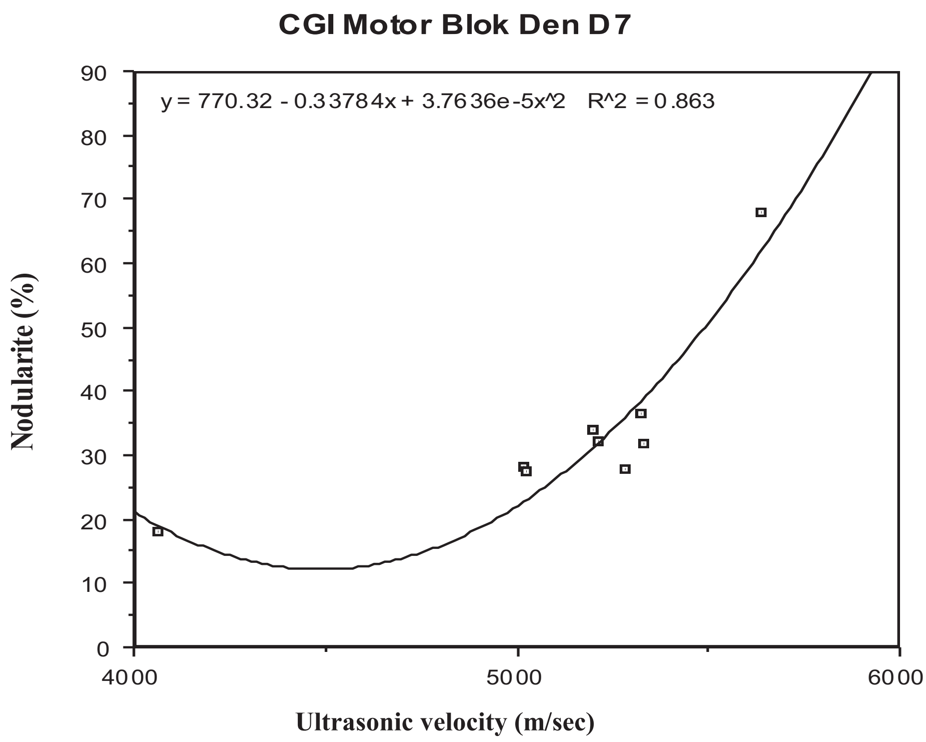


Figure 10. Ultrasonic test results of side by side step block castings and these values are used in order to get a velocity – average nodularity variation.

In this figure, spheroidal graphite % versus velocity (m/s) curve can be seen. After examination of the results, it can be seen that there is good correlation with the data produced for cast iron given in literature [6]. So it can be seen that when spheroidal graphite % increases, velocity (m/s) also increases

CONCLUSIONS:

1-The compacted graphite volume percent observed at different sections of the diesel engine blocks were found to be a function of cooling rate

2-The best CGI chemical compositions of the casting trials are in the range of CE:4.40-4.50 and corresponding Mg values are 0.017and 0.018

3-The cooling rates were found to be generally dependant on the section thickness but there are also exceptions in the filling and liquid metal flow sequence altering the cooling conditions.

4-Thin sections were found to be consisted of more spheroidal graphite structures but there are exceptions in arising form variation of local filling velocities and liquid metal flow loosing its sensible heat transfering more heat to the interior thin sections.

5-The nodularity values were measured by destructive technique. Specimens cut and prepared for optical microscope and then analyzed by image analzer yielded a directly increasing trend. Nodularity was found to be increasing with ultrasonic velocity. This diagram can be used to examine as cast and machined blocks without removing specimens form sections.

ACKNOWLEDGEMENTS:

Authors would like to acknowledge the financial support provided by TUBİTAK under the framework of Teydeb Project Number: 3070136

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