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CAIRO - EGYPT

PRODUCTION OF FERRITIC AND PEARLITIC GRADES OF SPHEROIDAL GRAPHITE CAST IRON BY THE INMOULD PROCESS

B.A. ELSARNAGAWY and M.TOLBA SALLAM*

ABSTRACT

The effect of inoculation efficiency and casting thickness on the final as cast structure of ductile iron castings was investigated. Four stages medium size,testing cluster weighting 56 Kg. was utilized to determine the required conditions for production of as cast ferritic structure in thin section castings. Each stage contained wedge shaped specimen with variable thickness from 2mm up to 25mm. Time elapse between inoculation and complete filling of each stage varied from 14 seconds for the first level to 56 seconds for the fourth level. Low magnesium ferro-silicon alloy 5% Mg(VL 63) was used as inoculant with average grain size 3-5mm. Inoculation was performed directly inside the mould utilizing special reaction chamber located in the runner. Microstructure observation and hardness tests were carried out on the obtained as cast structure of the four stage wedges. The chilling depth in each level was evaluated. A relation between time elapse from inoculation till solidification start and final as cast structure was established. The impact of casting thickness on the as cast structure was found to be less than that of inoculation efficiency. Ferritic and Pearlitic grades of spheroidal graphite cast iron can be obtained by control of inoculation parameters in case of inmould process

*Department of Materials and Processes, Military Technical College, Cairo,EGYPT.

INTRODUCTION

Nodularization treatment and graphitizing inoculation are two processes taking place simultaneously during inmould inoculation of ductile iron castings. A successful nodularization treatment requires magnesium content in the melt over 0.04% which ensures the spheroidal shape of graphite (1,2). Low magnesium ferro-silicon alloys are usually used as inoculants for inmould inoculation of ductile cast iron to reduce the violence accompanying dissolving of inoculant. The silicon introduced by the inoculant is responsible for the graphitizing action which takes place during inmould inoculation. Magnesium recovery during inmould process reaches 80% while in other modularizing methods it does not exceed 60%(3,4).

Fading of inoculant effect is overcomed by the last moment inoculation techniques where the inoculant is added just before pouring or directly inside the mould in special reaction chamber to minimize the time elapse between inoculation and filling of mould cavity (5,6). The efficiency of inoculation practiced by inmould process is reported to be much higher than that obtained by transfer ladel or sandwich methods(7,8). Even in the inmould inoculation process the fading problem is practiced in large castings where the inoculation efficiency varies from point to another (9,10).

The chemical composition of the melt and the casting wall thickness are usually the main controlling parameters of the as cast structure of ductile iron castings as reported by previous investigators (11,12). Recently investigations have been focused on utilization of the maximum inoculation efficiency as main governing parameter for controlling the matrix structure in ductile iron castings (12,13). This work aimed to study the inoculation efficiency variation at different points and its effect on the final as cast structure of inmould inoculated ductile iron castings.

EXPERIMENTAL PROCEDURE

Four stages test cluster equiped with reaction chamber for inmould inoculation was utilized to simulate a real medium size casting. The variation of inoculation efficiency at different points of the casting was investigated. Each stage consists of wedge shaped specimen with variable thickness from 2 mm up to 25mm connected with a horizontal rod of square cross section 40 x 40 mm, both are feeded from large cylinderical part of diameter d = 120 mm. This arrangement was designed to ensure 14 seconds delay time between filling of each stage and the next. Four Pt-Pt Rh 13 thermocouples were introduced at the top of the horizontal rods to indicate the complete filling of each stage as shown in the mould arrangement of the test cluster Fig. 1. The gating system was designed to maintain pouring rate of 1 Kg/sec. Total gross weight of the test cluster was 56Kg.

The melt was prepared in an induction furnace 100 Kg. capacity using special low sulphur pig iron. The chemical analysis of the melt before pouring is shown in table I.

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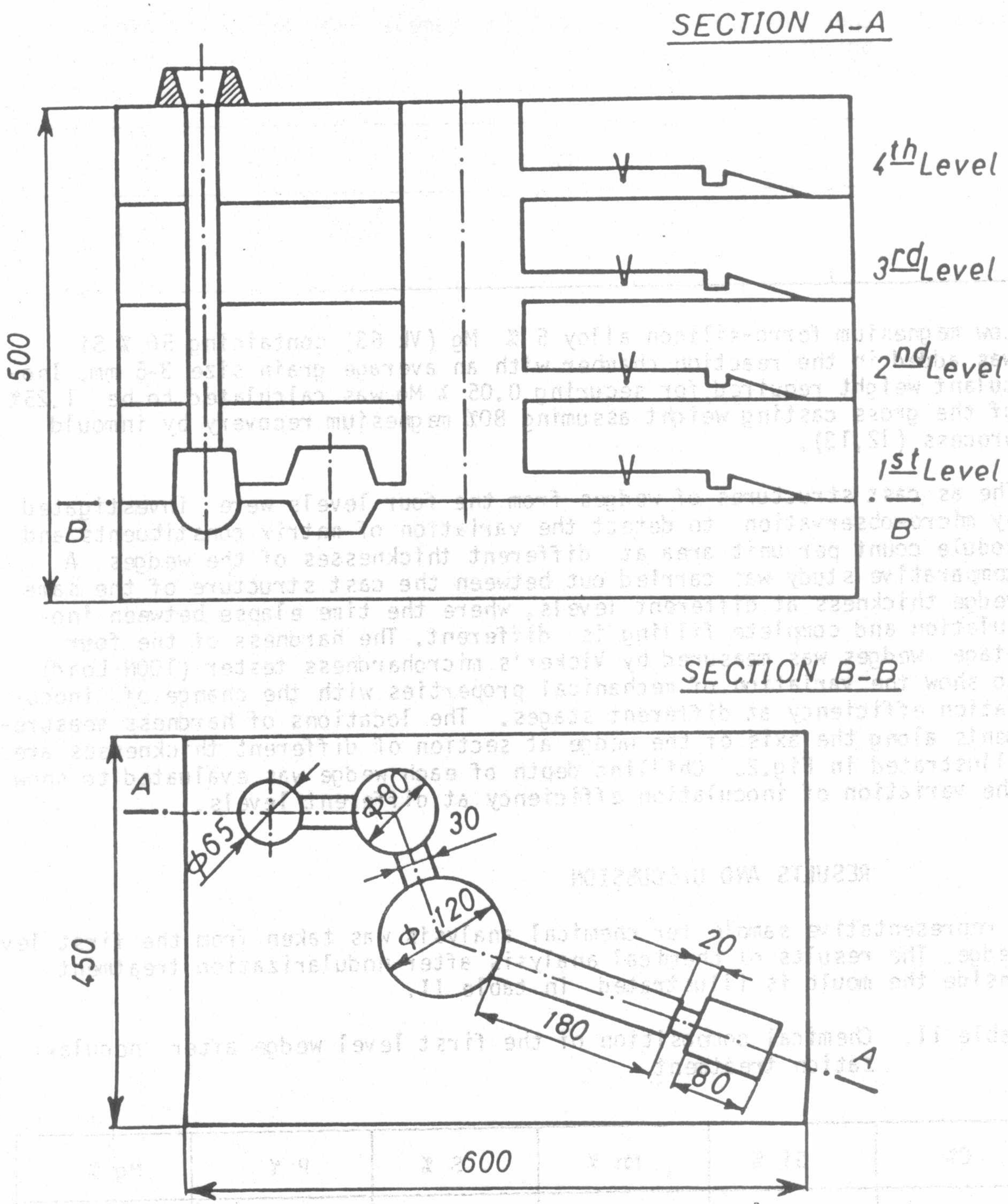

Fig.1. Mould arrangement of test cluster before pouring.

Table I. Chemical analysis of chilled sample from the melt before pouring.

C %	Si %	Mn %	S %	P %
3.7	2.2	0.5	0.01	0.04

Low magnesium ferro-silicon alloy 5 % Mg (VL 63) containing 50 % Si was added in the reaction chamber with an average grain size 3-5 mm. Inoculant weight required for securing 0.05 % Mg was calculated to be 1.25% of the gross casting weight assuming 80% magnesium recovery by inmould process (12,13).

The as cast structures of wedges from the four levels were investigated by micro-observation to detect the variation of matrix constituents and nodule count per unit area at different thicknesses of the wedges. A comparative study was carried out between the cast structure of the same wedge thickness at different levels, where the time elapse between inoculation and complete filling is different. The hardness of the four stage wedges was measured by Vicker's microhardness tester (100N Load) to show the variation of mechanical properties with the change of inoculation efficiency at different stages. The locations of hardness measurements along the axis of the wedge at section of different thicknesses are illustrated in Fig.2. Chilling depth of each wedge was evaluated to show the variation of inoculation efficiency at different levels.

RESULTS AND DISCUSSION

A representative sample for chemical analysis was taken from the first level wedge. The results of chemical analysis after nodularization treatment inside the mould is illustrated in table II.

Table II. Chemical composition of the first level wedge after nodularization treatment

C%	Si %	Mn %	S %	P %	Mg %
3.70	2.85	0.51	0.012	0.042	0.052

The magnesium recovery is enough to produce spheroidal graphite shape with 100% nodularization in the four levels. The results of hardness measurements of the four wedges at 8 locations along the axis of each wedge representing different thicknesses of casting are shown in table III, and graphically illustrated in Fig. 3.

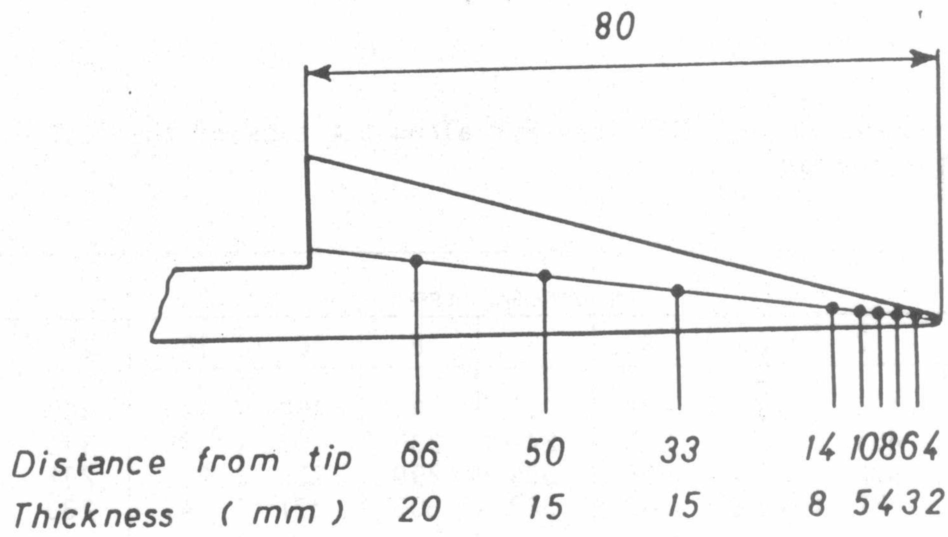

Fig.2. Positions of hardness measurements along the axis of the wedge at different thicknesses.

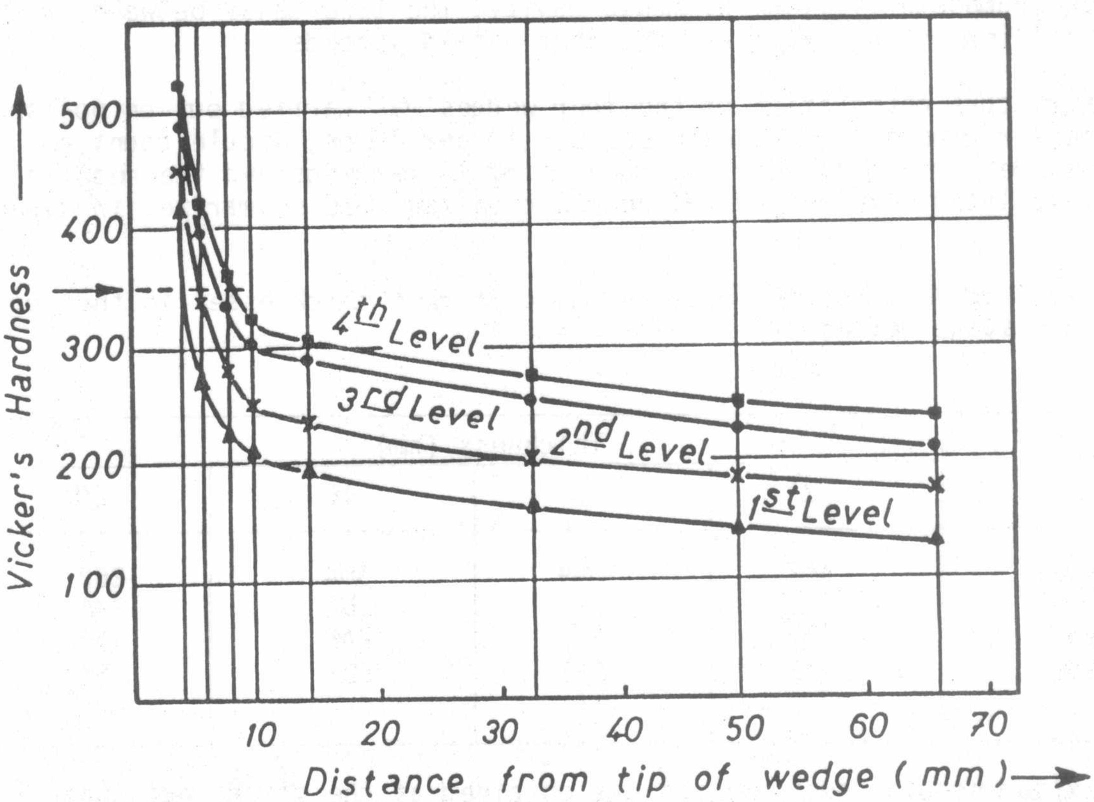

Fig.3. Hardness values measured along the axes of wedges at different levels.

Table III. Hardness values (HV) measured along the axes of the four level wedges.

Level	Thickness (mm)							
	2	3	4	5	8	10	15	20
1st Level	414	272	224	211	194	159	142	132
2nd Level	451	340	282	249	236	207	185	176
3rd Level	489	395	336	304	290	255	228	211
4th Level	522	418	360	322	303	271	247	233

The lower hardness obtained in the first level, if compared with the other levels, indicates the presence of higher ferrite percentage in the matrix. The chilling depth was estimated using the results of hardness tests and microstructure observation where the amount of ledeburite is less than 5% at 350 HV. Chilling depthes of the four level wedges are illustrated in Fig. 4. The recorded variation of the chilling depth from the first level to the fourth level wedges indicates that inoculation efficiency varies from level to another. Maximum inoculation efficiency is observed at the first level and decreases by increasing the time elapse between inoculation and complete filling of mould cavity. The time delay between complete filling of one level and the next was 14 seconds.

Mircostructure observation of the four wedges was carried out on polished surface for chosen four thicknesses 2,5,10 and 20 mm. Nodule count per unit area was determined at each location using 10 readings and the mean value was calculated. The results of nodule count/mm^2 are summarized in table IV.

Table IV. Nodule count/mm^2 obtained at different thicknesses in the four stage wedges

Level	Thickness (mm)			
	2	5	10	20
1st Level	402	349	304	262
2nd Level	381	341	258	241
3rd Level	359	303	246	197
4th Level	318	282	222	155

The maximum nodule count per mm^2 was obtained at the first level which indicates maximum inoculation efficiency. Comparing the module count per mm^2 at 5 mm thickness in the four levels we can remark that the number of nodules/mm^2 is dropping from 349 at the first level to 282 at the fourth level which can be explained by the fading of inoculant effect with filling

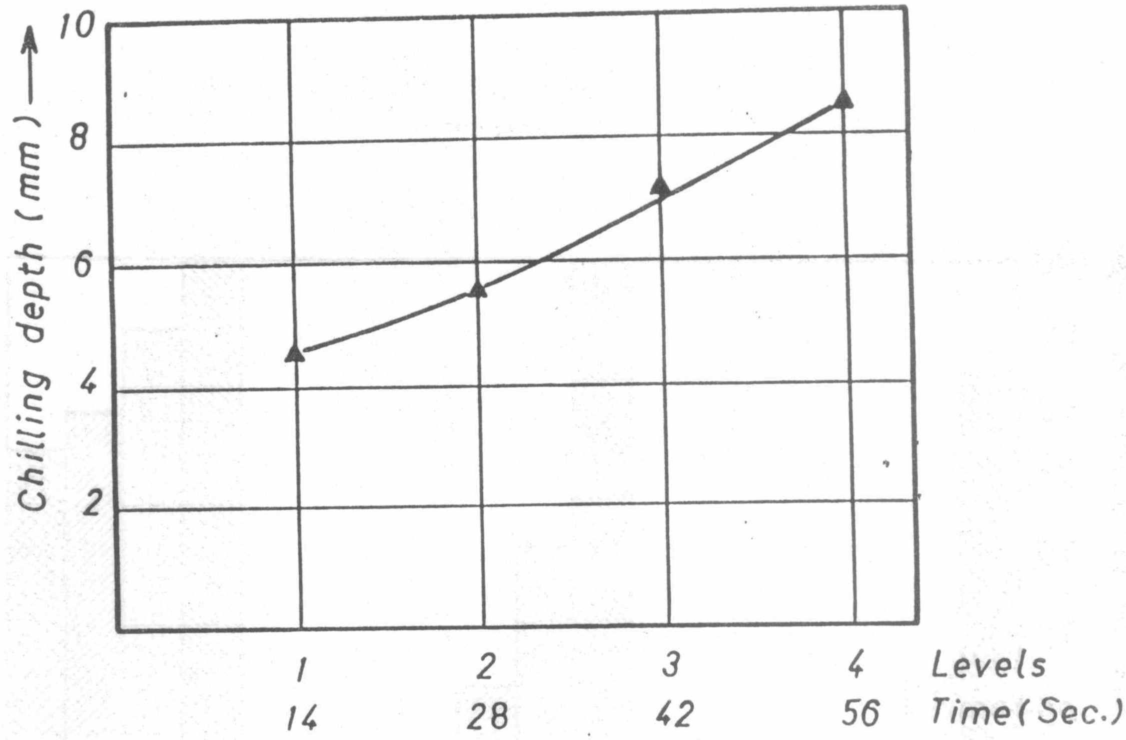

Fig.4. Dependence of chilling depth on time elapse between inoculation and filling of casting cavity.

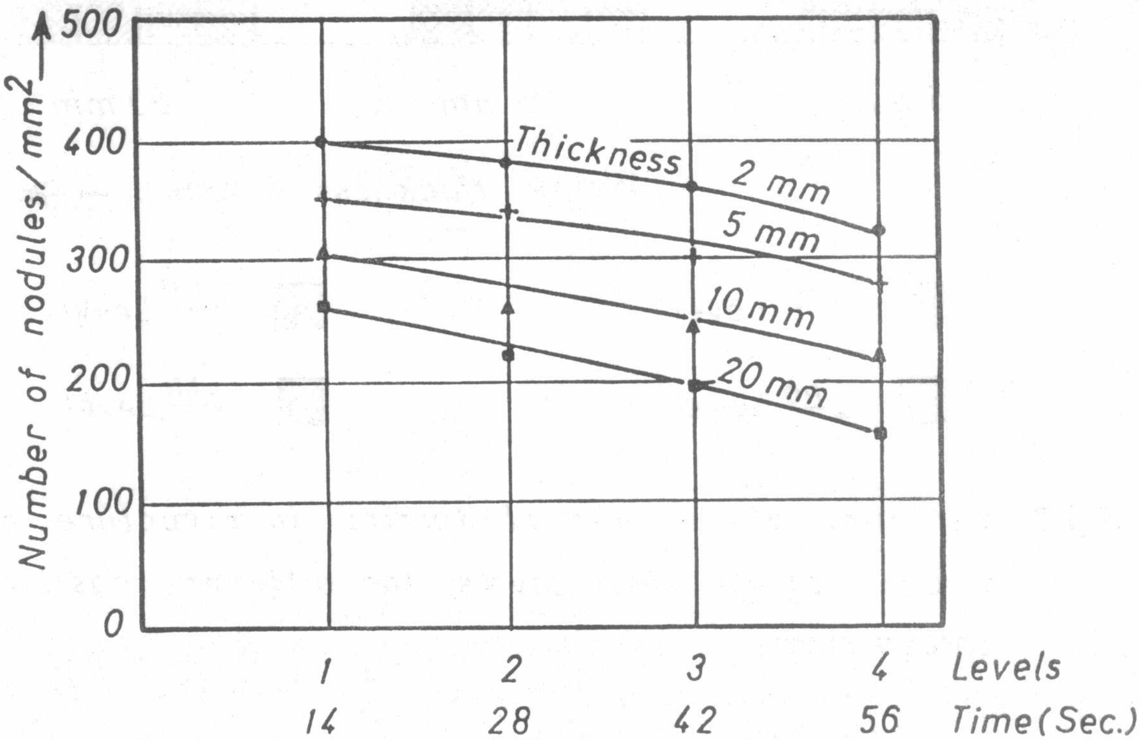

Fig.5. Dependence of number of nodules/mm^2 on time elapse between inoculation and filling of casting cavity at different thicknesses.

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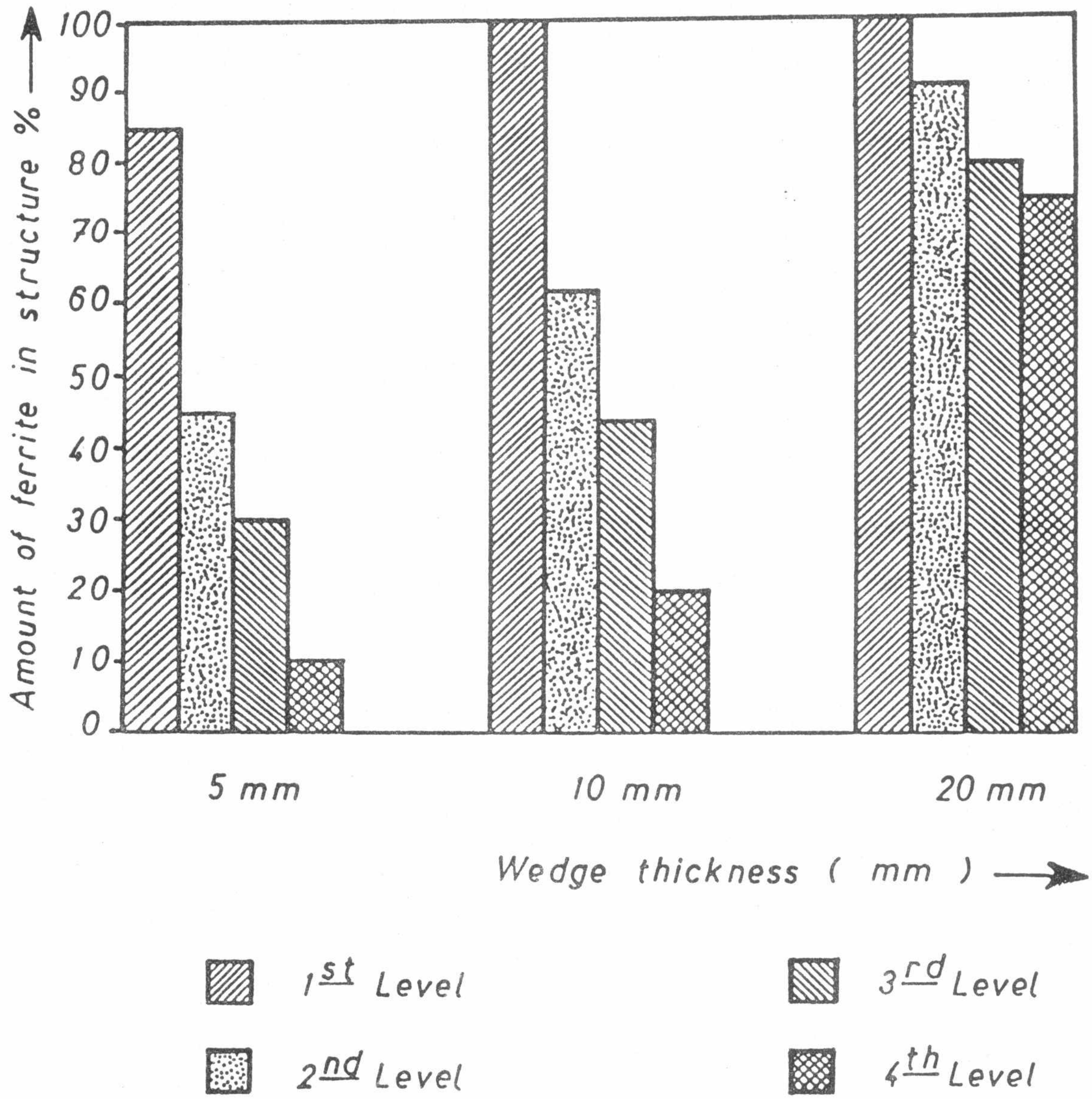


Fig.6. Variation of amount of ferrite in structure of wedges at the four levels for different casting thicknesses.

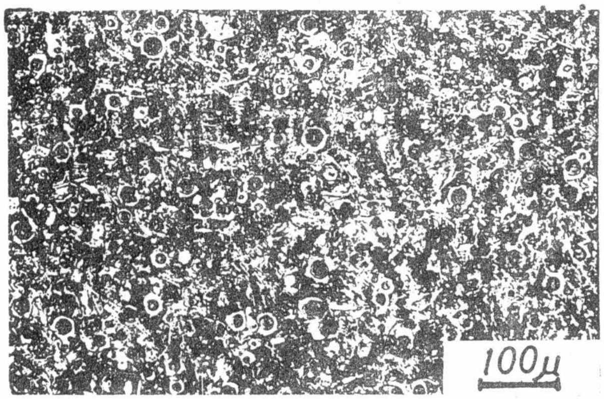
time. Fig. 5, illustrates the variation of nodule count per mm^2 at different levels and also at the same level due to variation of casting tickness. This variation of nodule count reveals the importance of the time elapse between inoculation and complete filling of mould cavity in controlling the resulting inoculation efficiency at different levels of the casting. The microstructure observation of Nital etched wedge sections showed the variation of ferrite amount in different levels for the same casting thickness. The amount of ferrite was measured at four locations representing different thicknesses of each wedge. The percentage of ferrite in the observed microstructure at 2,5,10 and 20 mm thickness are summerized in table V.

Table V. Ferrite amount measured at different thicknesses in the four stage wedges.

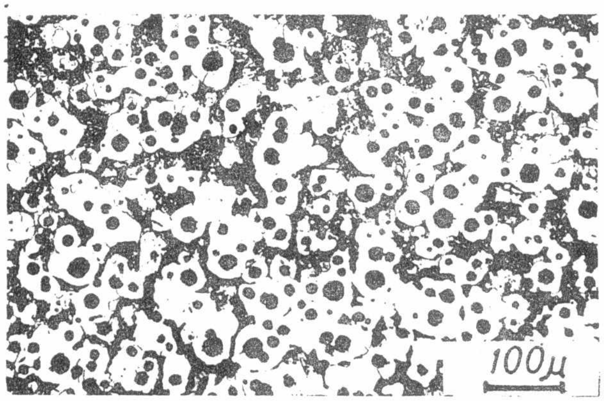
Level	Thickness (mm)			
	2	5	10	20
1st Level	0 %	85 %	100 %	100 %
2nd Level	0 %	45 %	62 %	91 %
3rd Level	0 %	30 %	44 %	80 %
4th Level	0 %	10 %	20 %	75 %

Fig. 6, shows the variation of ferrite content in the as cast structure of the four level wedges. The comparison of ferrite content in the four wedges at 5 mm thickness shows how the effect of high inoculation efficiency in the first level increased the ferrite content to about 85% while the same thickness at the fourth level had only 10% ferrite. At larger thickness the effect of inoculation efficiency is less recognized where at 20 mm thickness the first level showed 100% ferrite while the fourth level had 75 % ferrite. Representative microstructures of the four levels at 2, 5, 10, and 20 mm thickness are illustrated in Figs. 7,8,9 and 10 respectively, where we can notice that the amount of ferrite in the first level is much higher than that observed at higher levels. This may establish the facts that the efficiency of inoculation controls the final as cast structure and the amount of ferrite is less sensitive to section size if the inoculation efficiency is high enough. Consequently ferritic matrix can be obtained even at thin sections if high efficiency of inoculation is secured. At lower inoculation efficiency the effect of casting thickness on the final structure is more clear as in the case of the fourth level wedge where the ferrite amount changes from 10% to 75% at 5 mm and 20 mm thickness respectively.

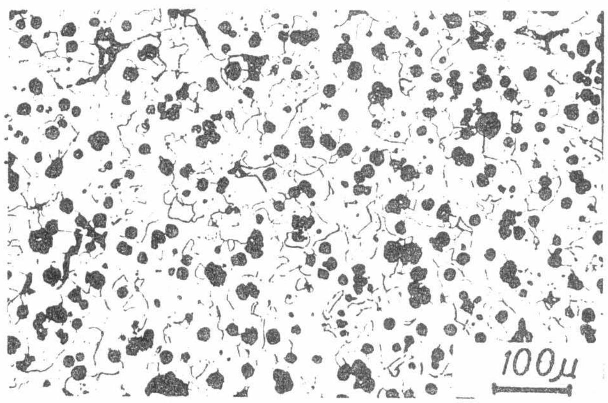
The efficiency of inoculation practiced by the inmold process is much higher than that obtained by transfer ladle or sandwich method (14,15). In ladle inoculation the nodule count for the thickness 10 mm does not exceed 150 nodules/mm^2 while in the inmould process it reaches 304 nodules/mm^2 for the first level and even for the fourth level it reaches 222 nodules/mm^2. The minimum inoculation efficiency obtained in the fourth level is still higher than transfer ladle inoculation.



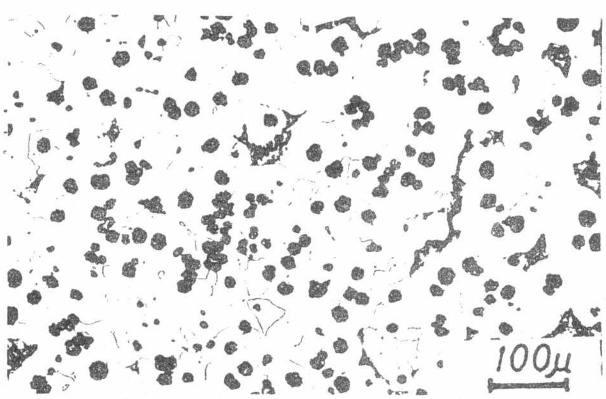
2 mm thickness
Nº of nodules/mm^2 = 402
Chilled structure



5 mm thickness
Nº of nodules/mm^2 = 349
Ferrite amount = 85%

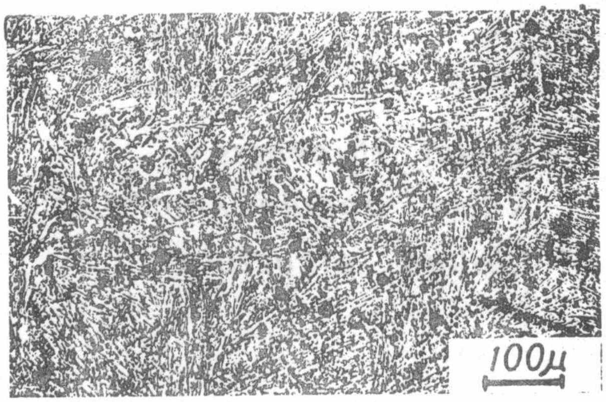


10mm thickness
Nº of nodules/mm^2 = 304
Ferrite amount = 100%

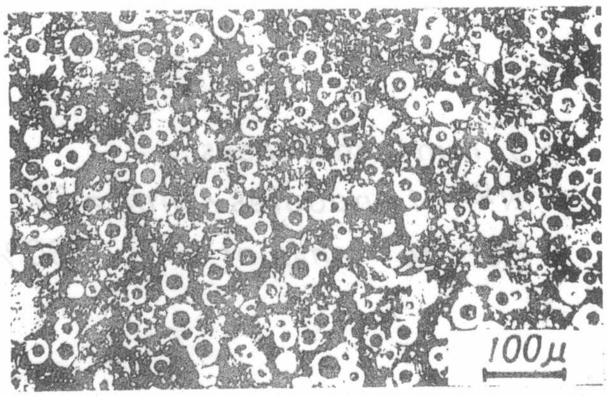


20 mm thickness
Nº of nodules/mm^2 = 262
Ferrite amount = 100%

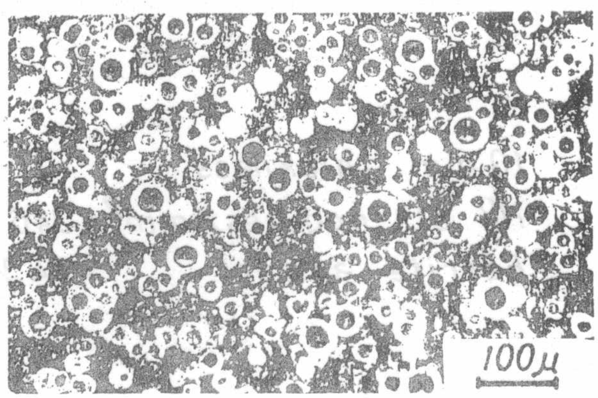
Fig.7. Microstructures of the first level obtained at 2, 5, 10 and 20 mm thicknesses.



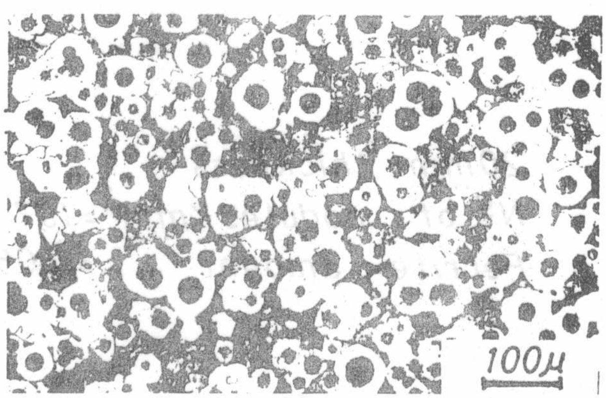
2 mm thickness
Nº of nodules/mm^2 = 381
Chilled structure



5 mm thickness
Nº of nodules/mm^2 = 341
Ferrite amount = 45%

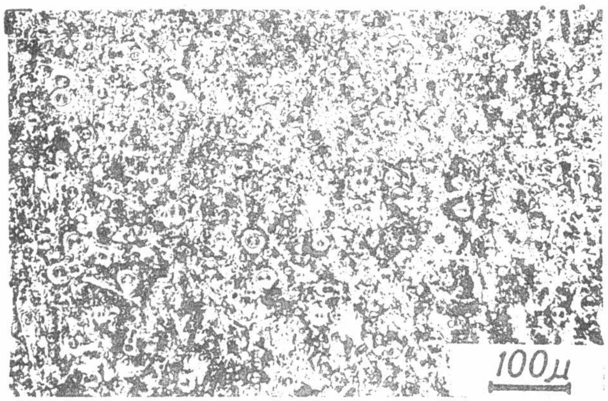


10 mm thickness
Nº of nodules/mm^2 = 258
Ferrite amount = 62%

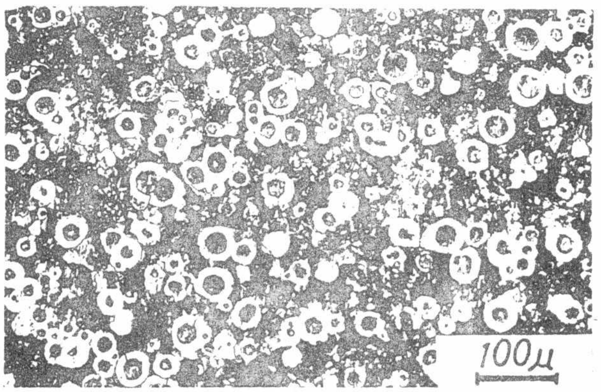


20 mm thickness
Nº of nodules/mm^2 = 241
Ferrite amount = 91%

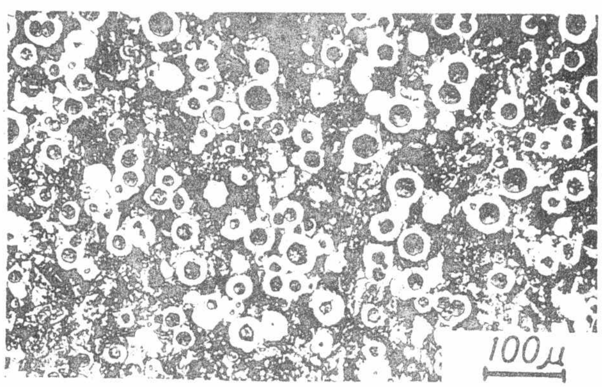
Fig.8. Microstructures of the second level obtained at 2, 5,10 and 20 mm thicknesses.



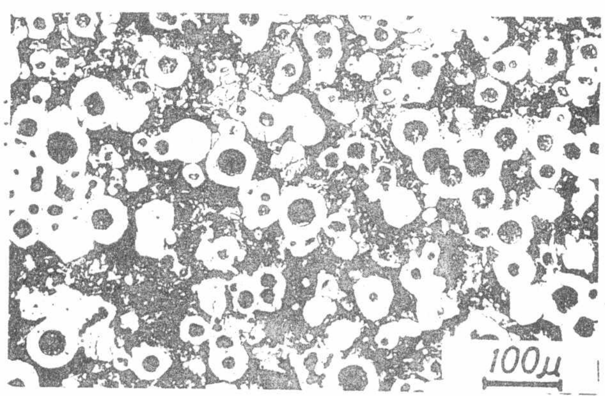
2 mm thickness
Nº of nodules/mm^2 = 359
Chilled structure



5 mm thickness
Nº of nodules/mm^2 = 303
Ferrite amount = 30%

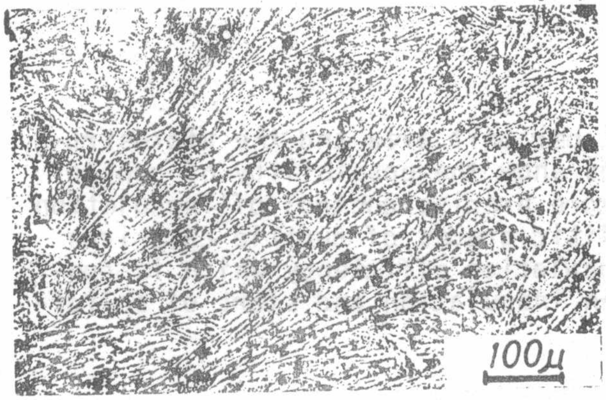


10 mm thickness
Nº of nodules/mm^2 = 246
Ferrite amount = 44%

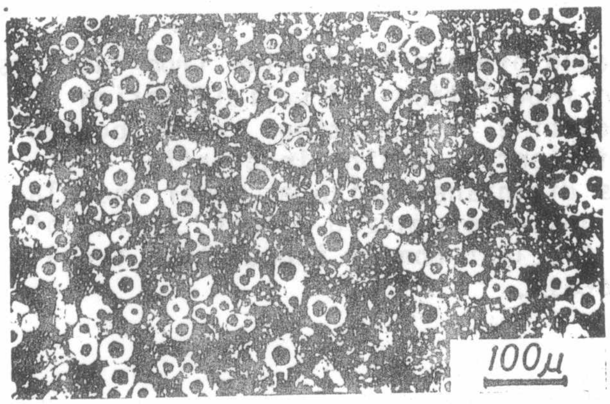


20 mm thickness
Nº of nodules/mm^2 = 197
Ferrite amount = 80%

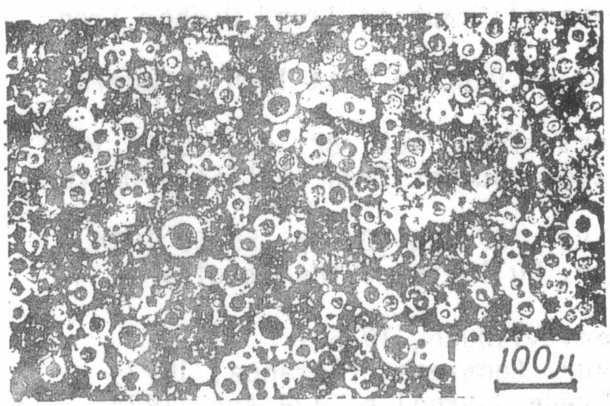
Fig.9. Microstructures of the third level obtained at 2, 5, 10 and 20 mm thicknesses.



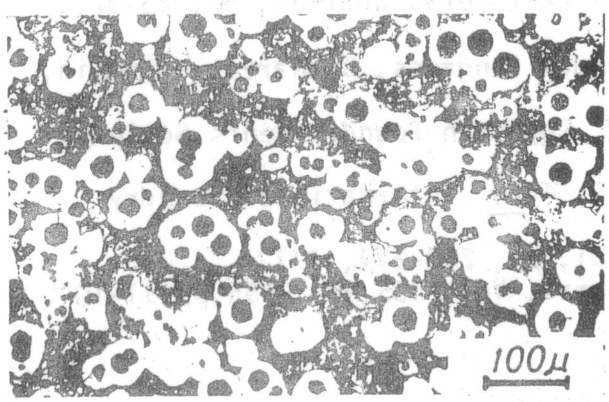
2 mm thickness
Nº of nodules/mm^2= 318
Chilled structure



5 mm thickness
Nº of nodules/mm^2= 282
Ferrite amount =10%



10 mm thickness
Nº of nodules / mm^2= 222
Ferrite amount = 20%



20 mm thickness
Nº of nodules/mm^2= 155
Ferrite amount = 75%

Fig.10. Microstructures of the fourth level obtained at 2, 5, 10 and 20 mm thicknesses.

The observed variation of nodule count per unit area and the microstructure variation at the different stages show the possibility of controlling the final as cast structure by more precise control of inoculation efficiency. Ferritic or ferritic-pearlitic grades of ductile cast iron can be produced using the suitable inoculation efficiency which is controlled through the time elapse between inoculation and start of solidification process.

CONCLUSION

The efficiency of inoculation of inmould process in ductile iron castings is affected by the time elapse between inoculation and solidification start. The as cast microstructure of ductile iron castings can be controlled by the control of inoculation efficiency. At high inoculation efficiency the effect of casting thickness diminishes while at lower inoculation efficiency the casting thickness has a recognized effect. Fading of inoculation effect is a fact even in the last moment inoculation techniques such as the case of inmould process.

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