ARCHIVES
of
FOUNDRY ENGINEERING

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

ISSN (1897-3310)
Volume 11
Issue 3/2011

101 – 106

20/3

Role of the preliminary heat treatment in anisothermic eutectoid change of the cast iron

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Received 04-05-2011; accepted in revised form 06-05-2011

Abstract

Preliminary heat treatment, preceding continuous cooling of the iron casting, assumed in the research, complies with the applied in practice single normalization, double normalization or normalization with slow cooling. In each of these cases continuous cast iron cooling has been begun from the same temperature 925°C. CCT diagrams have been made with use of metallographic method. The mechanism, kinetics and the final structure of eutectoid change of the cast iron after such treatment have been traced.

Keywords: Ductile Cast Iron, Heat Treatment, CCT Diagrams

1. Introduction

Single normalization, double normalization or normalization with steady cooling in the range of supercritical temperatures [1÷5]. Belong to ways of normalizing of spheroidal cast iron which are most often used in the practice. Each of these ways of normalization should lead to receiving higher pearlite content in the matrix, therefore to increase of strength properties with the retaining of the definite ductility minimum.

Heat treatment preceding the final air-cooling will have impact on the degree of cast iron homogeneity, size of the austenite grain, saturation ratio of cast iron with austenite carbon [3]. Factors mentioned above will in turn shape the propensity of the cast iron to take on pearlite structure as a result of eutectoid change.

Answer to the question – how does the preliminary heat treatment influences the eutectoid change – may be given by CCT diagrams made with preservation of the conditions stimulating the authentic heat treatment.

2. The material, program and test methods

For the examination purposes ordinary cast iron of chemical constitution given in Table 1 has been used.

Table 1.
The chemical composition in ductile iron

The content of the component % mas							
C	Si	Mn	P	S	Cr	Ti	Mg
3,53	2,81	1,14	0,11	0,015	0,01	0,10	0,08

Cast iron has been smelted in a hot-blast cupola furnace, from the hematite hot metal and scrap iron. Spheroidization has been carried out in container of the cupola with use of ML5 alloy rods. Modification with ferrosilicon Fe-Si 75 has been carried out in a hot-metal runner. Cast iron has been cast to wet moulds in form of YII wedge-shaped samples (PN-EN 1563:2000 norm). After pouring cast iron has ferritic-pearlitic matrix (24% volumetric ferrite, 0,6% cementite). 9,7% volumetric of the cast iron is nodular graphite Gf 7, which occurs in quantity of 107 releases per 1 mm 2 of the microsection. From the cubicoid parts of YII specimens the samples (20 mm in diameter and 3 mm thick) for metallographic examination have been cut out.

For the purpose of the examination of the impact which preliminary heat treatment has on eutectoid change of the cast iron the following heat treatment variants have been assumed:

- variant I – single normalization (Fig. 1)

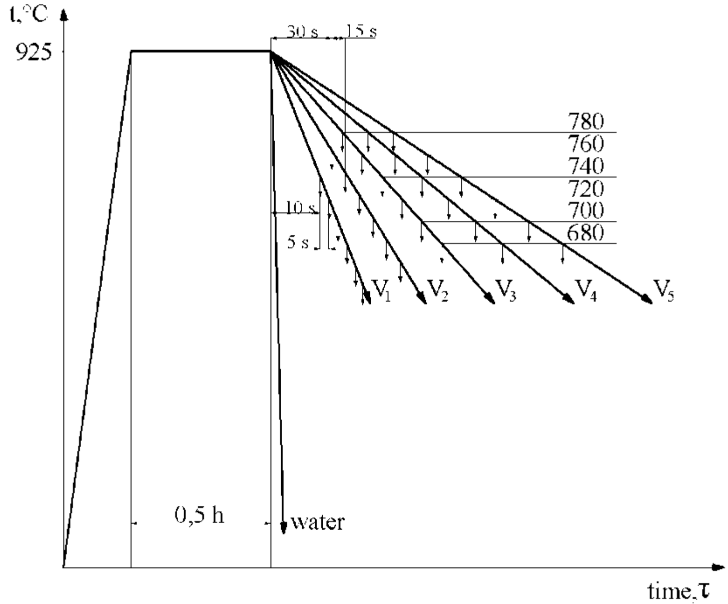

Fig. 1. Heat treatment scheme according to variant I

- variant II – double normalization (Fig. 2)

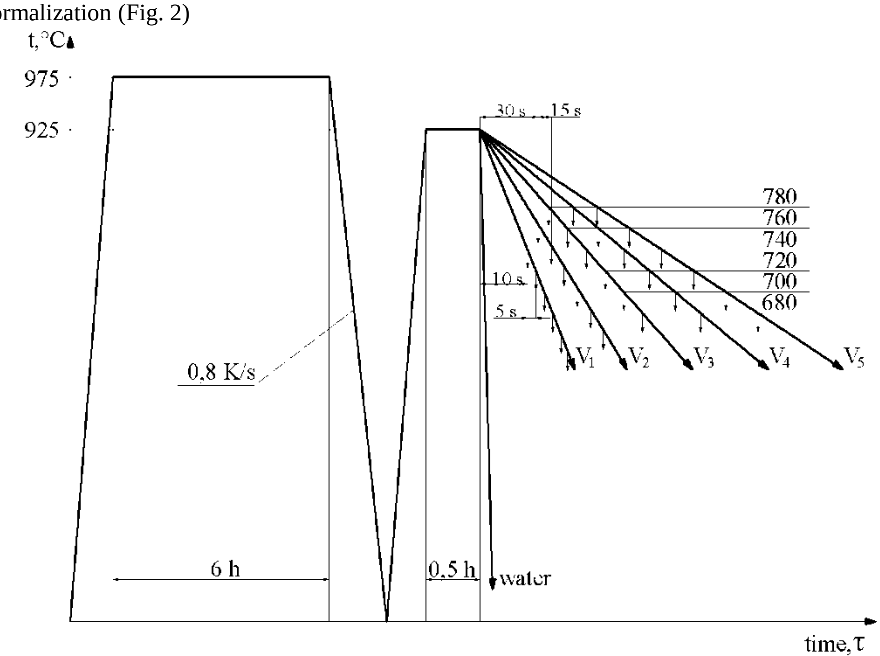

Fig. 2. Heat treatment scheme according to variant II

- variant III – normalization with slow cooling (Fig. 3)

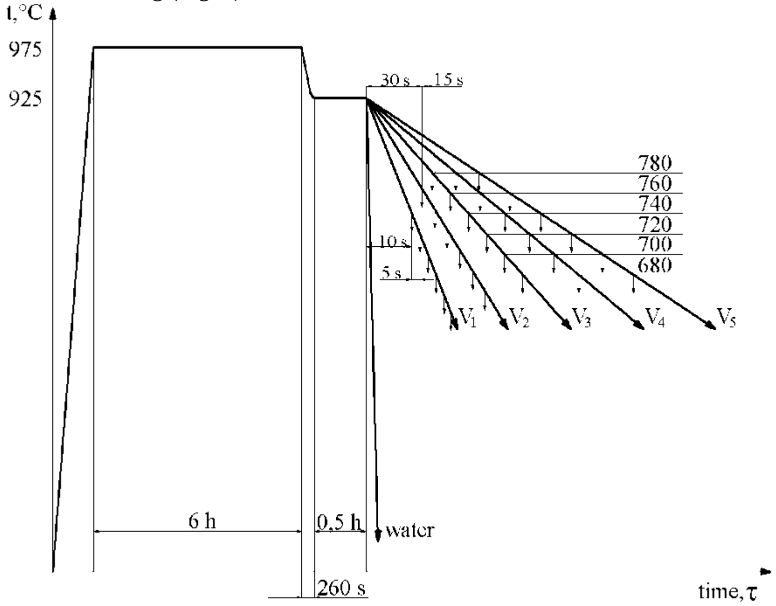

Fig. 3. Heat treatment scheme according to variant III

Carrying out of the test had a following run: kit of seven samples hanged on a spatial grip has been heated in vertical, tubular dilatometer and austenitized according to variants assumed (Fig. 1÷3). Then the sample kit has been cooled in a way which enabled one to receive determined cooling speed. The biggest cooling speed V1 has been received through cooling of the sample kit in calm air. The other speeds have been received with use of a low-temperature pipe furnace of the isothermal dilatometer. After receiving a required temperature (speeds V3, V4, V5) or after the determined cooling time passed (speeds V1, V2) each sample in turn has been quenched in water. In each variant first sample has been hardened directly from the temperature received from austenitizing in water. Selection of time value or temperature from which the samples were quenched have been based on the earlier research on this cast iron sort. For the determined cooling speed one test has been carried out. During cooling the cooling curve has been registered with use of NiCr–Ni thermoelement, which was capacitively welded with the last cooled sample. In order to secure samples from oxidation they have been galvanically coated with nickel and dilatometer furnace has been flushed with argon.

After heat treatment the samples were cut (or broken) along the diameter and metallographic specimens etched with natal have been made. On the base of linearly approximated quantitative metallographic analysis results the temperature of the austenite change in 1 or 99% degree for individual cooling speeds as well as temperature of austenite change in 1 or 50% pearlite and 1% ferrite have been determined. Temperature values determined in such way have been marked on the corresponding cooling curves, receiving CCT diagrams. Samples hardened directly in water have been subjected to diffractional X-ray examination.

C_M percentage in martensite has been determined from the formula [11]:

; (1)

where:
c, a – lattice parameters of the unit cell of martensite, nm

Carbon contents in austenite C_A has been calculated from the formula [6]:

; (2)

where:
a – lattice parameter of austenite, nm

Volumetric fraction of austenite V_A has been calculated from the formula [12]:

; (3)

where:
- total intensity with regard to doublet martensite lines (110-011),
- total intensity with regard to austenite line (111),
- coefficient = 0,85.

Average cooling speed values in the temperature range 800÷650°C have been depicted in table 2.

Table 2.
Average cooling speed

The variant of the processing	The speed of the cooling, °C/s				
	V_1	V_2	V_3	V_4	V_5
I	8,25	1,26	0,46	0,26	0,03
II	8,80	1,17	0,42	0,23	0,03
III	8,90	1,16	0,42	0,23	0,02

3. The results of investigations and their analysis

On the base of metallographic analysis of cast iron cooled with speed V_1, V_2 or V_3 (cooling speed from 8,9 ÷ 0,42°C/s) it can be observed that the eutectoid change begins simultaneously according to stable and metastable system, independently from the preliminary heat treatment variant. The only exception is cast iron treated according to variant I, where in speed V_1 eutectoid change begins only in metastable system. Clear differences in the change mechanism are observed between cast iron treated according to variant I and variants II and III, where this change proceeds very similarly.

Ferrite in cast iron cooled with speed V_1, V_2, V_3 in each case increased from the boundary austenite-graphite.

Pearlite crystallizes in the initial stage of change in the cast iron treated according to variant I in resolute predominance in the neighbourhood of hypereutectoid cementite grains in boundary range of the eutectoid grains. In case of cast iron treated according to variants II and III, pearlite crystallizes in the initial stage of the change both from the boundary A/G, F/A, in form of insulated grains in austenite and in contact with hypereutectoid cementite that has not dissolved yet.

Cooling with speed V_3 leads to forming of ferrite halo around graphite. Pearlite increases intensively from the boundary A/F, where thick ferrite halo has already been formed. As a result of cast iron cooling with speed V_4 or V_5 (0,26 ÷ 0,02°C/s) the first product of the eutectoid change is exclusively ferrite, independently from the preliminary heat treatment applied. Ferrite grains increase from graphite or in austenite, forming a irregular network. Pearlite nucleates and increases in the initial change phase from the boundary of eutectic grains and after the ferrite halo reaches thickness from the boundary F/A as well. Final structure of cast iron cooled with speed V_4 is pearlitic-ferritic and with speed V_5 ferritic – pearlitic.

On the base of quantitative metallographic analysis the diagram depicting ferrite and pearlite content after finishing the eutectoid change as function of cooling speed has been made.

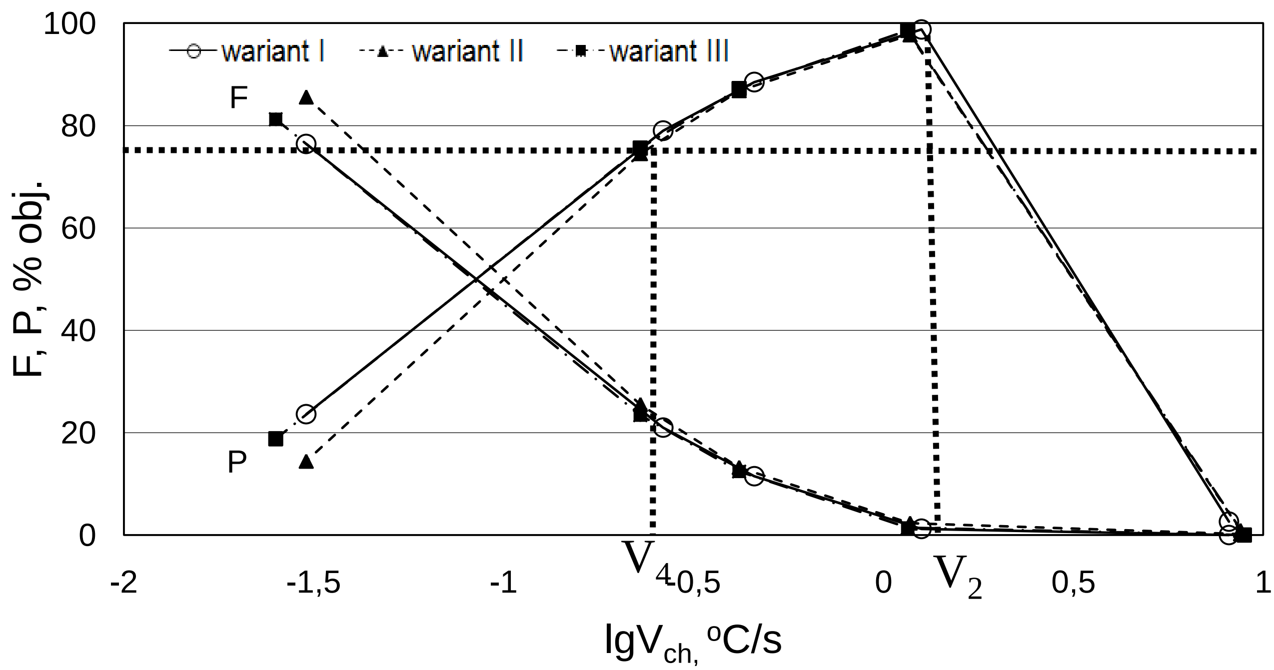

Fig. 4. Final structure after the eutectoid change

On the base of linearly interpolated quantitative metallographic analysis results the diagrams CCT for cast iron treated according to variant I (Fig. 5), variant II (Fig. 6) and variant III (Fig. 7) have been made.

Contour lines depicting the start of the eutectoid change complying with the process of the austenite change in quantity 1% have been marked on the diagrams. Change rate η = 1% for speed V_1 – V_3 constitutes the sum of pearlite and ferrite content, and for speed V_3 – V_4 change rate η = 1% complies with process of changing austenite into ferrite. Contour line of the end of the change complies with sum of the ferrite and pearlite content η = 99%. On the diagrams contour lines corresponding to process of pearlitic reaction of austenite in quantity 1 or 50%.

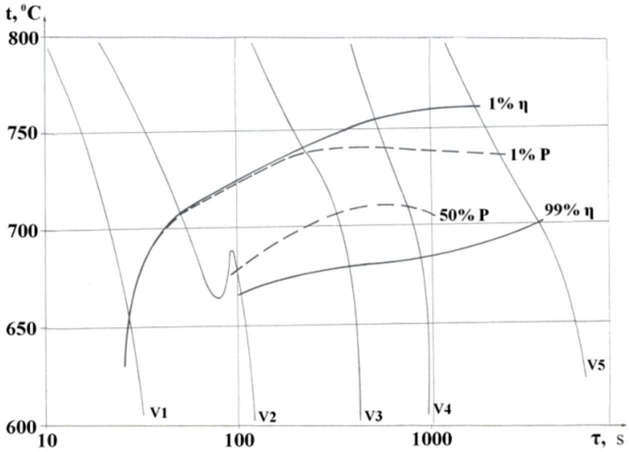

Fig. 5. CCT diagram of cast iron treated according to variant I

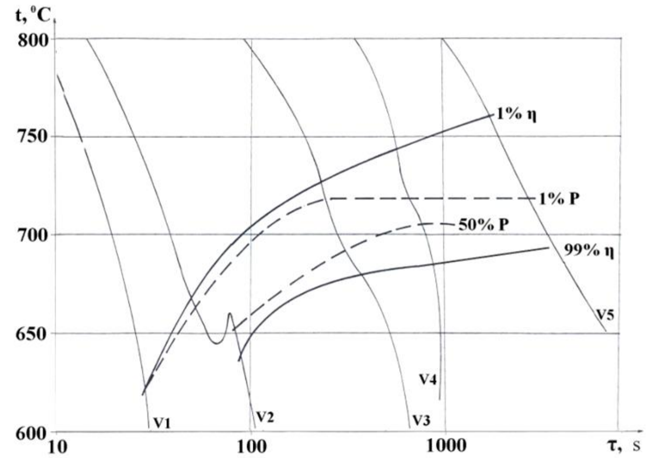

Fig. 6. CCT diagram of cast iron treated according to variant II

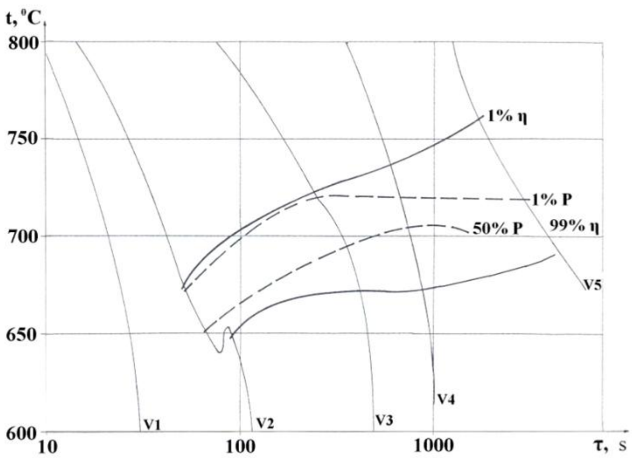

Fig. 7. CCT diagram of cast iron treated according to variant III

On the cumulative diagram the statement of lines representing start and end of eutectoid change for individual variants has been depicted (Fig. 8).

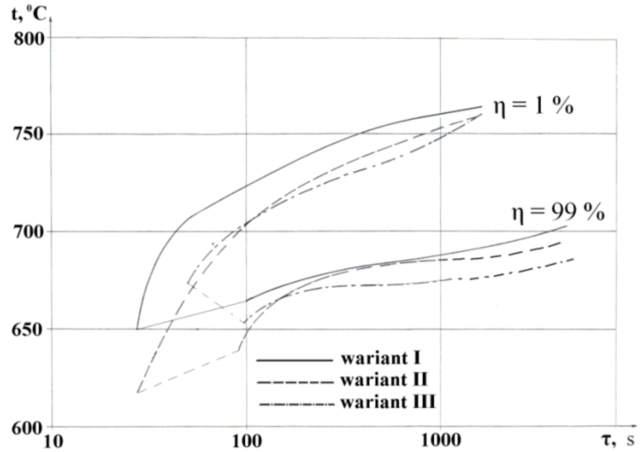

Fig. 8. Curves of start and end of the eutectoid change of cast iron treated according to variants I, II, III

From the picture 8 it turns out that variants which have been applied influence the kinetics of eutectoid change. Bigger homogenization of cast iron (variant II and III) trigger off the shift of the start and end lines to the lower temperature range and shift of the CCT diagram according to time axis vector („to the right"). Very clear is the influence of treatment variant on the position of the pearlitic change contour line (Fig. 9).

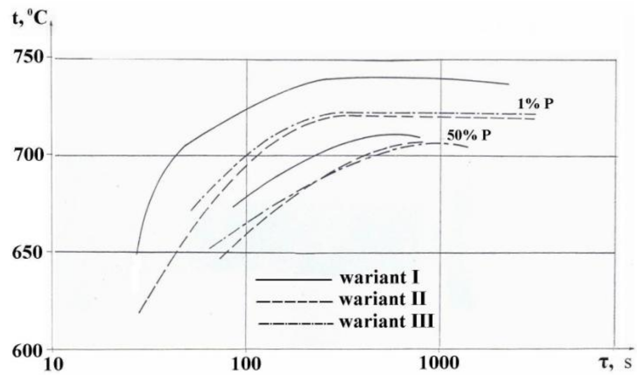

Fig. 9. Contour lines depicting austenite change in 1 or 50% pearlite for individual variants

Contour lines of the austenite change in 1 or 50% pearlite for cast iron treated according to variant I are much above (in higher temperature) than the others. The differences in position of the course of these lines between variants II and III are insignificant (Fig. 9).

The results of diffractive X-ray examination of samples hardened directly from the austenitizing temperature have been depicted in Table 3.

Table 3.
The results of diffractive X-ray examination

Heat treatment variant	Coal content in martensite, % mas.	Coal content in austenite, % mas.	Austenite content, % vol.	Coal content in cast iron matrix*
I	0,72	0,72	15,9	0,72
II	0,73	0,67	14,6	0,72
III	0,68	0,72	13,1	0,69

* Coal content in matrix has been calculated as weighted average of coal content in martensite and austenite

Differences in the coal content in austenite and in matrix between individual heat treatment variants are insignificant. Therefore one should assume that structural and chemical homogeneity of the cast iron has the essential impact on the difference in kinetics and structural composition after eutectoid change.

4.Conclusions

The heat treatment variants that have been applied influence the mechanism, kinetics as well as final quantitative composition of the matrix structure. In cast iron cooled with speed bigger than V_3 (0,42 ÷ 0,46°C/s) eutectoid change begins simultaneously according to stable and metastable system (variant I – cooling speed 8,25°C/s). In inhomogeneous cast iron which contains hypereutectoid cementite (ca. 0,6%) pearlitic change nucleates in boundary ranges of eutectic grains (variant I). In cast iron which has been homogenized through long-lasing austenitizing the pearlitic change nucleates from the boundary austenite-graphite as well.

Bigger homogenization of the cast iron treated according to variants II and III causes decrease of the temperature of start and end of the eutectoid change. Particularly decreases the temperature of the pearlitic change and shift of CCT diagrams „to the right" occurs, therefore a increase of the cast iron hardenability.

Normalization of the cast iron should lead to the increase of the pearlite content in comparison with initial state. All three variants lead to the same target, is the cooling speed is expressed between 0,23 and 1,26°C/s (V_2 ÷ V_4).

The differences in the pearlite content for individual variants in this cooling speed range are very small. From the economic point of view the variant I would be the most beneficial one. However, homogenization of the cast iron treated according to variant II and III may result in better plastic properties and impact resistance.

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