www.czasopisma.pan.pl PAN www.journals.pan.pl

ARCHIVES
of
FOUNDRY ENGINEERING

ISSN (2299-2944)
Volume 2020
Issue 3/2020

37 – 40

10.24425/afe.2020.133327

7/3

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

Ductile Cast Iron Microstructure Adjustment by Means of Heat Treatment

M. Mróz [a],*, A.W. Orłowicz [a], M. Tupaj [a], B. Kupiec [a], M. Kawiński [b]
[a] Rzeszow University of Technology, Al. Powstańców Warszawy 12, 35-959 Rzeszów, Poland
[b] Cast Iron Foundry KAWMET, ul. Krakowska 11, 37-716 Orły, Poland
*Corresponding author. e-mail address: mfmroz@prz.edu.pl

Received 16.07.2019; accepted in revised form 01.10.2019

Abstract

The study presented in this paper concerned the possibility to apply a heat treatment process to ductile cast-iron thin-walled castings in order to remove excessive quantities of pearlite and eutectic cementite precipitates and thus meet the customer's requirements. After determining the rates of heating a casting up to and cooling down from 900°C feasible in the used production heat treatment furnace (v_h = 300°C/h and v_c = 200°C/h, respectively), dilatometric tests were carried out to evaluate temperatures T_{gr}, TAc_1^{start}, TAc_1^{end}, TAr_1^{start}, and TAr_1^{end}. The newly acquired knowledge was the base on which conditions for a single-step ferritizing heat treatment securing disintegration of pearlite were developed as well as those of a two-step ferritization process guaranteeing complete disintegration of cementite and arriving at the required ferrite and pearlite content. A purely ferritic matrix and hardness of 119 HB was secured by the treatment scheme: 920°C for 2 hours / v_c = 60°C/h / 720°C for 4 hours. A matrix containing 20–45% of pearlite and hardness of 180–182 HB was obtained by applying: 920°C for 2 hours or 4 hours / v_c = 200°C/h to 650°C / ambient air.

Keywords: Ductile cast iron, Heat treatment, Microstructure

1. Introduction

The cast iron with ferritic and ferritic-pearlitic matrix is a structural material widely used in automotive and machine-building industries [1]. The ferritic matrix can be obtained in cast iron either by means of primary crystallization through proper selection of chemical composition and conditions of the casting process, or by way of secondary crystallization occurring in the course of heat treatment processes. The latter option is used commonly in foundries to correct the structure of already cast articles in case when, despite correctly performed selection of chemical composition, excessive quantities of pearlite and eutectic cementite precipitates have appeared in the structure in the course of solidification of the castings. This results usually in obtaining higher values of hardness, exceeding those determined in the customer's specification constituting usually a part of the casting acceptance criteria.

The literature of the subject offers a plurality of reports on studies concerning the choice of parameters for gray cast-iron ferritizing heat treatment aimed at improvement of the resistance to cracking [2–4] or the fatigue strength [5].

A number of the proposed cast-iron heat treatment schedules consists in heating the material up to temperatures from the range $T_{gr} – TAc_1^{start}$ and holding it, at a selected temperature, for a period of time ensuring disintegration of pearlite into ferrite and graphite. These relatively low soaking temperatures result in lower susceptibility of cast iron to superficial decarburization.

It should be also borne in mind that in the course of heating a cast iron with its matrix containing pearlite, disintegration of the latter into ferrite and graphite commences at the graphitization start temperature (T_{gr}) which is lower then the temperature of eutectoid transformation end at heating (TAc_1^{start}). For a large group of unalloyed spherical graphite cast irons, the graphitization start temperature is about 600°C and increases with increasing material heating rate.

In case of a cast iron containing eutectic cementite, the problem of removing the latter becomes more complicated as this may involve the need for applying annealing temperatures higher than the temperature of eutectoid transformation end at heating (TAc_1^{end}) [6]. To acquire the knowledge about specific values of the temperature parameter, it is necessary to perform dilatometric tests. In view of the fact that the temperatures defining the start and the end of the eutectoid transformation depend on the cooling rate, one has to evaluate the heating rate and the cooling rate characterizing the furnace used to carry out the target heat treatment process in conditions of being filled with a batch of castings.

The objective of the study presented herein was to determine such parameters of a ferritizing heat treatment for ductile cast iron castings used to fabricate components of fireplace inserts which would decrease the share of pearlite and eliminate eutectic cementite precipitates from the matrix.

2. The material and the methodology

The material used in the present study were ductile cast-iron thin-walled (280x240x5 mm) castings (3.6% C, 2.4% Si, 0.4% Mn, 0.03% P, 0.01% S, Fe to balance), with a pearlitic-ferritic matrix, in which the share of pearlite exceeded 70% and castings containing about 80% of pearlite and precipitates of eutectic cementite.

To be able to correct the microstructure in scope of removal of excessive pearlite and eutectic cementite precipitates, it was necessary to undertake a study aimed at developing such heat treatment schedules which would allow to obtain 20–45% of pearlite in castings without any traces of eutectic cementite precipitations, as provided in the product acceptance criteria. Hardness of castings with such microstructure should be included within the range from 170 HB to 230 HB.

The first step of the study consisted in determining the feasible rate of heating a batch of castings in the heat-treatment, electric furnace (SSKTW 1150/1, a capacity of 3500kg) up to temperature 900°C and the rate of cooling the batch down to the ambient temperature. It has turned out that the heating rate was 300°C/h, and the cooling rate was 200°C/h.

Dilatometric tests were performed with the use of a modified dilatometer LS-4 equipped with a computer-based specimen temperature and elongation recording system. To determine the eutectoid transformation start and end temperatures at heating, the tests were made for the heating rate of 300°C/h, the austenitizing temperature of 920°C, the austenitizing time of 30 minutes, and the cooling rate of 200°C/h.

Observations of microstructure were carried out with the use of NEOPHOT 2 optical microscope.

Hardness of the specimens was measured on a Brinnel hardness tester with a penetrator in the form of a ball with diameter of 10 mm.

3. Study results and discussion

An example microstructure of a ductile iron casting containing unacceptable share of pearlite and cementite precipitations is shown in Figure 1.

The dilatometric curve for heating and cooling of the examined ductile cast specimen taken from the casting is presented in Figure 2.

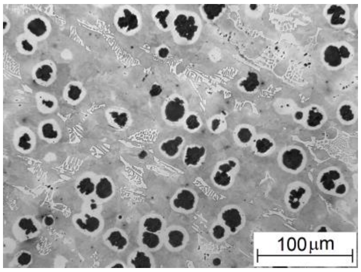

Fig. 1. Microstructure of a scrapped casting. Section etched in 4% HNO_3. Pearlite, ferrite, eutectic cementite, graphite.
Hardness 270 HB

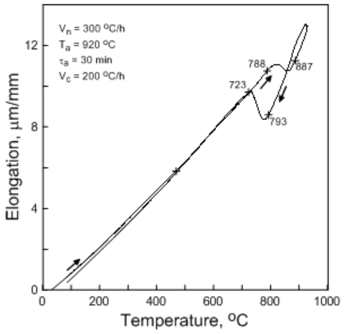

Fig. 2. A dilatometric curve for heating and cooling a ductile cast specimen taken from the casting

Heat treatment at a temperature from the range T_{gr} –TAc_1^{start}

It has been assumed the temperature used to soak the castings would be lower than the TAc_1^{start} value, and specifically 720°C. For this very heat treatment temperature, the adopted soaking time was 5 hours followed by final cooling in ambient air.

Microstructure of a casting after such thermal treatment is presented in Figure 3.

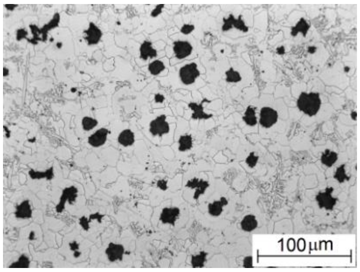

Fig. 3. Microstructure of a ductile iron casting after annealing at temperature 720°C for 5 hours, and then cooled in air. Ferrite, eutectic cementite, graphite. Unetched section.
Hardness 255 HB

The obtained results indicate that the applied heat treatment scheme failed to ensure complete decomposition of eutectic cementite although significant refinement of the latter could be observed. In view of the above, it has been decided to increase the temperature of the ferritizing annealing process to the value of 750°C and adopt the same soaking time of 5 hours followed by cooling in air. Microstructure of the casting after such heat treatment is shown in Figure 4.

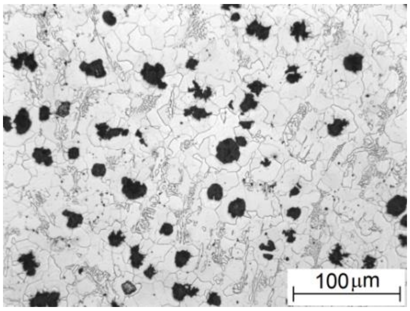

Fig. 4. Microstructure of a ductile iron casting after annealing at temperature 750°C for 5 hours and then cooled in air. Ferrite, cementite, graphite. Section etched in 4% HNO_3. **Hardness 250 HB**

The obtained results indicate that the applied schedule of heat treatment was unable to ensure decomposition of eutectic cementite precipitations.

Heat treatment at a temperature above TAc_1^{start}, and then at a temperature below TAr_1^{end}

It has been assumed that the austenitizing temperature of 900°C would be applied. With results published in [6] taken into account, it has been decided that the casings would be soaked at the temperature for 25 minutes, and then cooled at the rate of 60°C/h down to temperature 720°C. After being held at the temperature for 30 minutes, they would be further cooled in air down to the ambient temperature. Microstructure of castings heat-treated this way is shown in Figure 5.

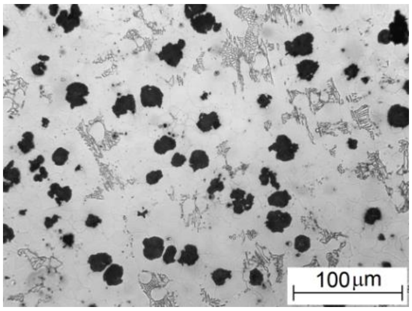

Fig. 5. Microstructure of a ductile iron casting after annealing at 900°C for 20 minutes, cooling at rate of 60°C/h to 720°C, and holding at the temperature for 30 minutes, followed by cooling in ambient air. Unetched section. Graphite, ferrite, eutectic cementite. **Hardness 237 HB**

It has been found that the adopted time of soaking at temperature 900°C was to short to ensure decomposition of eutectic cementite. Based on the obtained results, it has been decided that the soaking temperature would be increased to 920°C and the soaking time extended to 2 hours. The treatment included a slow cooling (60°C/h) to 720°C, followed first by holding at the temperature for 4 hours, and then cooling in air down to the ambient temperature. Microstructure of castings heat-treated that way is shown in Figure 6.

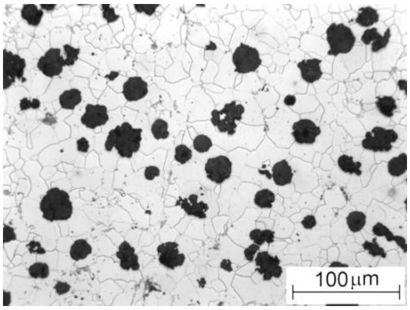

Fig. 6. Microstructure of a ductile iron casting after annealing at temperature 920°C for 2 hours, cooling at 60°C/h to 720°C, holding at the temperature for 4 hours, and final cooling in ambient air. Etched in 4% HNO. Ferrite, graphite. **Hardness 119 HB**

It has turned out that the adopted time of soaking at the temperature of 920°C was able to secure disintegration of eutectic cementite, but the conditions of cooling and soaking at temperatures below TAr_1^{end} resulted in development of purely ferritic matrix. For this reason, the obtained hardness value was too low compared to the value determined in the customer's requirements.

Based on the obtained results, decision was taken to increase the cooling rate to 100°C/h for the process of cooling the casting down to temperature 650°C. The austenitizing conditions, i.e. 920°C for 2 hours, were left unchanged. Microstructure of a casting heat-treated this way is presented in Figure 7.

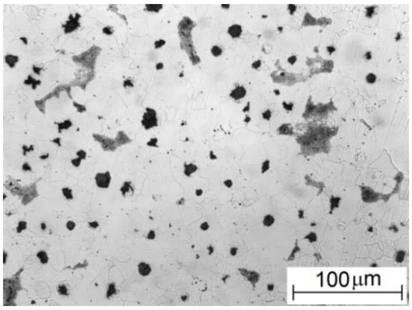

Fig. 7. Microstructure of a ductile iron casting after annealing at temperature 920°C for 2 hours and cooling at the rate of 100°C/h to 650°C followed by cooling in ambient air. Section etched in 4% HNO_3. Magnification 100×. Ferrite, pearlite, graphite. **Hardness 128 HB**

It has turned out that the time of austenitizing at 920°C was long enough to ensure disintegration of eutectic cementite, but the cooling conditions (100°C/h) failed to secure the satisfactory content of pearlite which, as before, resulted in obtaining a casting showing hardness too low compared to the value determined in the customer's acceptance criteria. For this reason, decision has been taken to increase the cooling rate to 200°C/h when cooling the casting down to 650°C. The austenitizing conditions, 920°C for 2 hours, were left unchanged. Microstructure of a casting heat-treated this way is shown in Figure 8.

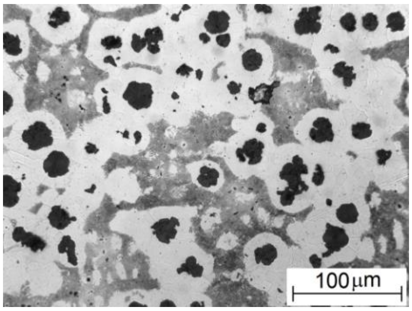

Fig. 8. Microstructure of a ductile iron casting after annealing at temperature 920°C for 2 hours, cooling down to temperature 650°C at rate 200°C/h, and final cooling in ambient air. Section etched in 4% HNO_3.Pearlite, ferrite, graphite. **Hardness 182 HB**

The obtained results evidence satisfactory hardness of the casting consistent with requirements defined by the customer.

To ensure complete decomposition of eutectic cementite, it was necessary to apply the austenitizing time longer than this reported in [6] (20 minutes).

It seemed to be an interesting issue to determine the effect of the austenitizing time at temperature 920°C on microstructure and hardness of castings, at the cooling conditions the same as before (200°C/h). A new austenitizing time of 4 hours has been adopted. Microstructure of a casting heat-treated this way is presented in Figure 9.

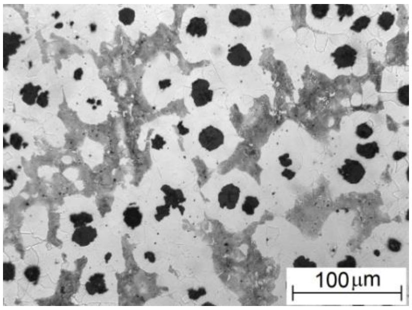

Fig. 9. Microstructure of a ductile iron casting after annealing at temperature 920°C for 4 hours, cooling down first to 650°C at rate of 200°C/h and then in ambient air. Section etched in 4% HNO_3. Pearlite, ferrite, graphite.
Hardness 180 HB

It has been found that when the castings were austenitized at temperature 920°C for 4 hours, more uniform distribution of pearlite in the matrix was obtained, compared to the thermal treatment schedule in which the same temperature value was adopted but with shorter austenitizing time (2 hours).

4. Conclusions

The obtained results indicate that those of the adopted heat treatment schedules which comprised soaking the cast iron at temperatures from the range T_{gr}– TAc_1^{start} (720°C for 5 hours or 750°C for 5 hours), were unable to secure decomposition of eutectic cementite precipitates, but turned out to be efficient in decomposition of pearlite precipitations.

By subjecting the castings to heat treatment according to the schedule consisting in austenitizing at temperature 920°C for 2 hours or 4 hours followed by cooling down to temperature 650°C at the rate of 200°C/h and final cooling in ambient air, it was possible to obtain the required microstructure of matrix (20–45% pearlite, ferrite being the rest) and hardness 180–182 HB.

The heat treatment schedule which included austenitizing for 4 hours can be claimed the most favorable one in view of the obtained hardness value and pearlite content.

Acknowledgements

The present paper reports results of a study carried out as part of the Operational Programme Smart Growth, Project POIR.01.01.02-00-0113/16-00, Measure 1.1 “Enterprises' R&D projects”, Sub-measure 1.1.2 “R&D works relating to fabrication of pilot/demonstrator plant”, implemented jointly by the Rzeszów University of Technology and KAWMET Iron Foundry.

References

[1] Verdu, C., Hdrien, J. & Reynaud, A. (2005). Amélioration des propriétés de fatigue de fontes GS par traitments thermiques de type Dual Phase. *Hommes&Fonderie*. 352, 30-33.

[2] Monchoux, J.P., Verdu, C. & Fougeres, (2000). Effect of a ferritization heat treatment on the fracture toughness of ferritic spheroidal graphite cast iron. *Scripta Materialia*. 42, 1047-1052.

[3] Iacoviello, F. & Cocco, V.D. (2016). Influence of the graphite elements morphology on the fatigue crack propagation mechanisms in a ferritic ductile cast iron. *Engineering Fracture Mechanics*.167, 248-528.

[4] Iacoviello, F., Cocco, V.D. & Bellili, C. (2019). Overloaded effect on fatigue cracks in a ferritized ductile cast iron. *International Journal of Fatigue*.127, 376-381.

[5] Shirani, M. & Härkegård, G. (2011). Large scale axial fatigue of ductile cast iron for heavy section wind tube components. *Engineering Failure Analysis*. 18,6, 1496-1510. DOI: 10.1016/j.engfailanal.2011.05.005.

[6] Giacopini, A., Boeri, R.E. & Sikora, J.A. (2003). Carbide dissolution in thin wall ductile iron. *Materials Science and Technology*. 19, 1755-1760.