QUANTITATIVE ANALYSIS OF SELECTED PARAMETERS OF THE MICROSTRUCTURE OF ADI WITH THE ADDITION OF Ni

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Abstract

The article presents the results of computer quantitative analysis of the microstructure of ductile cast iron heat treated with isothermal transformation. To determine the relative volume fraction of austenite and the geometric parameters of ferrite needles the methods of image analysis were used. Analysis of the effect of temperature and time of austempering on the volume fraction of austenite and the dimensions of the ferrite needles was carried out.

Keywords: Austempered ductile iron (ADI), image analysis

1. INTRODUCTION

The aim of the heat treatment process of ductile iron is to rebuild its microstructure, most commonly based on pearlitic matrix, and to obtain cast iron with matrix composed of ausferrite. Ausferrite is a microstructural constituent of ductile iron matrix obtained as a result of the austempering treatment. It is composed of ferrite in the form of needle-like plates and thermodynamically stable austenite with high carbon content. Cast iron characterized by this type of structure is called ausferritic cast iron. The cast iron with graphite in the form of spheroids is also referred to as ADI (Austempered Ductile Iron) [1, 2]. The ductile iron with ferritic - austenitic matrix structure has gained great popularity among the manufacturers of machines, owing to a beneficial combination of high strength, good ductility and fracture toughness [3]. The type of the obtained microstructure is very significantly influenced by the chemical composition of the base (ductile) iron and the properly selected values of heat treatment parameters. These factors significantly influence the parameters metal matrix constituent such as length of the needles of ferrite and the volume fraction of austenite in matrix. These parameters are closely correlated with the mechanical properties of ADI. The finer are the precipitates of ferrite plates and the lower is the content of austenite in cast iron matrix, the higher is the strength and hardness of the material, while high elongation is achieved through increased content of austenite and coarse precipitates of ferrite plates. The authors of this study present an analysis of the parameters of the cast iron microstructure with a specific chemical composition depending on the austempering time and temperature. The article discloses the results of computer image analysis, which was carried out on images of microstructures of the examined cast iron for different variants of heat treatment. During the analysis, parameters of the cast iron matrix, including the relative volume fraction of austenite and the length of ferrite needles, were determined.

Studies are also available which as a main aim have the manufacture of a new type of ductile iron with carbides, in which the desired microstructure of the metal matrix is obtained without the use of heat treatment, i.e. in the as-cast state, through proper quantitative combination of alloying elements. This cast iron is manufactured by the Inmold process [4, 5].

2. TEST MATERIAL

Tests were carried out on ductile iron of the chemical composition given in **Table 1**. Melts were made at the Foundry Research Institute in Cracow using an induction medium frequency RADYNE furnace with crucible of

100 kg capacity and an inert lining. The spheroidization treatment of cast iron was performed by Sandwich Process at 1400 °C using a slender ladle. From the ductile iron, keel blocks were cast according to ASTM A897 (**Figure 1**).

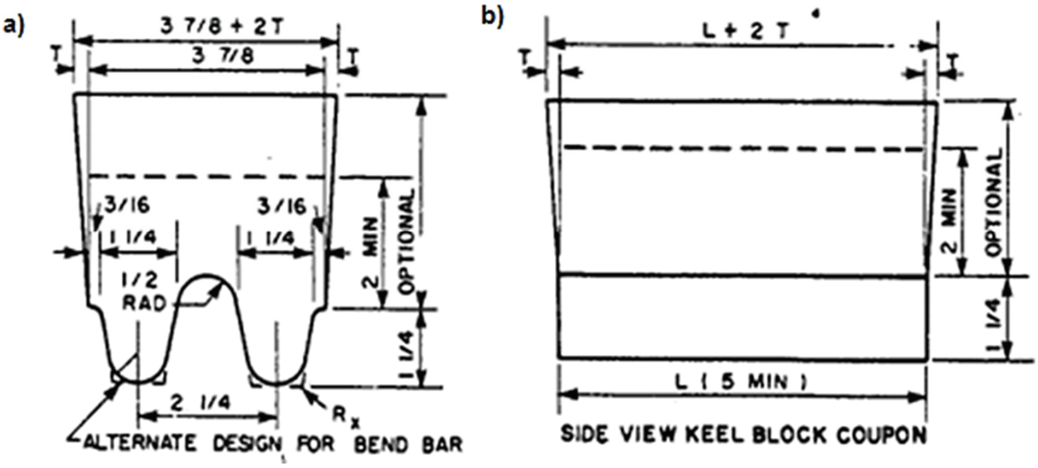


Figure 1 A schematic of the keel block cast acc. to ASTM A897, a) front view, b) side view

Table 1 Chemical composition of the tested cast iron (wt. %)

C	Si	Mn	Mg	Ni	P	S
3.55	2.55	0.31	0.063	1.56	0.025	0.009

The test specimens were cut out from the lower part of the keel block and were next austempered according to the heat treatment variants developed previously. Fixed austenitizing conditions (temperature of 920 °C and time of 120 min) were selected and 6 variants of the austempering treatment were applied. Choosing the temperature of austempering based on the developed TTT diagram (**Figure 2**), the area of the occurrence of the bainitic transformation was split into two ranges, i.e. upper range and lower range. Three values of the austempering temperature were selected for each of the ranges, different for the lower range and upper range. A detailed list of the heat treatment variants is presented in **Table 2**.

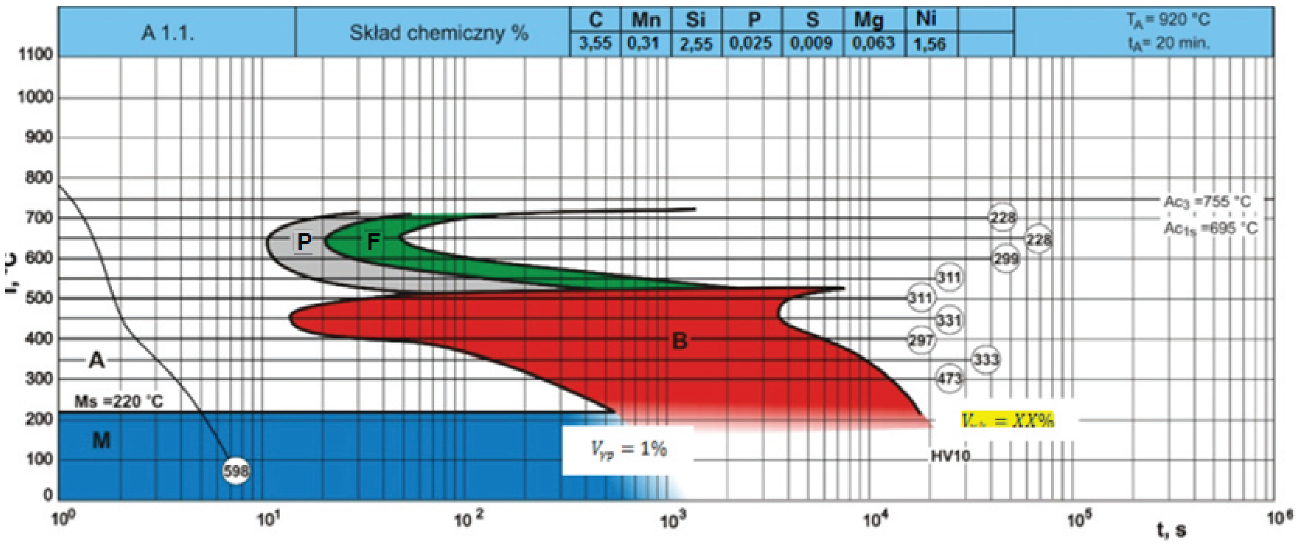


Figure 2 TTT diagram

Table 2 Summary of different variants of the conducted heat treatment

Trans-formation range	Designation of HT variant	T_{pi}, °C	τ_{pi}, min
Upper	W2	260	120
	W4	300	120
	W6	330	120
Lower	W8	360	90
	W10	380	90
	W12	400	90

3. RESEARCH METHODOLOGY

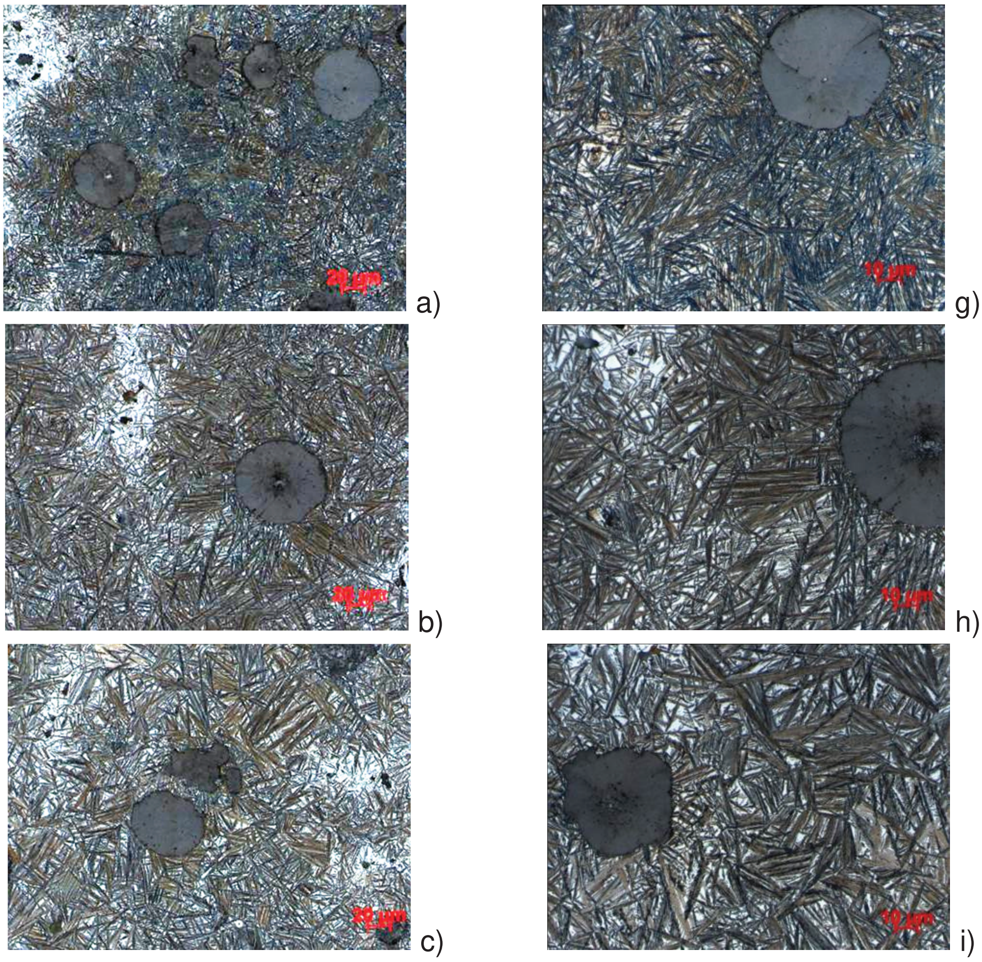
3.1. Metallographic examinations

Metallographic sections of ADI after several variants of heat treatment were etched in the Mi1Fe reagent according to PN-61 / H-04503 standard. One selected metallographic section of ADI (W8) was etched in the B-M reagent of the following chemical composition: 100 ml of base solution (10 parts by volume of H_2O, 1 part by volume of concentrated HCl), 2 g NH_4F • H, 1 g $K_2S_2O_5$. This reagent does not dye austenite and carbides, but it colours bainite and tempered martensite in brown, and martensite in blue. Sometimes fine martensite needles are not tinged in blue but in light brown, and then in the assessment of microstructure it is their morphology that should be taken into account.

W2
T = 260 °C,
t = 120 min

W4
T = 300 °C,
t = 120 min

W6
T = 330 °C,
t = 120 min



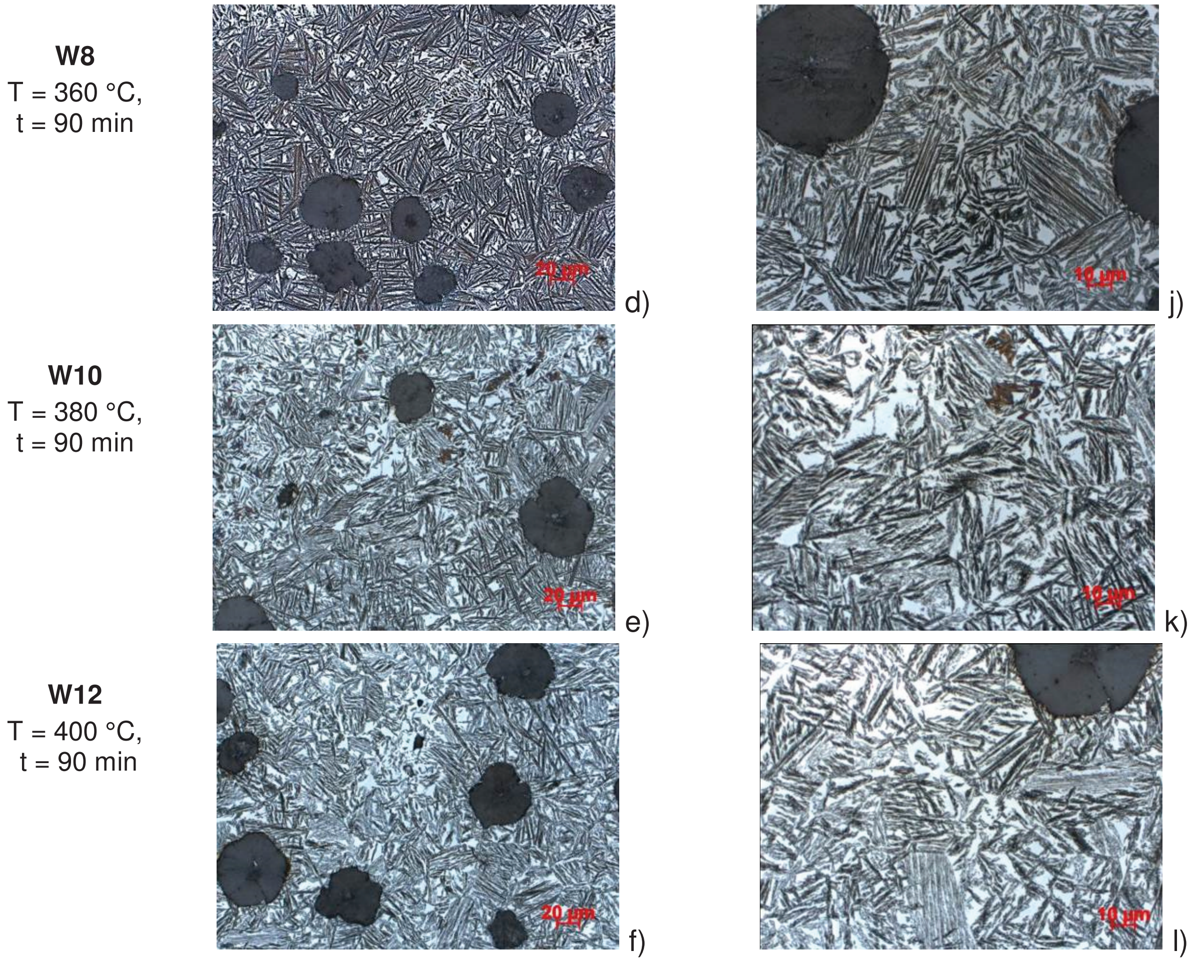


Figure 3 Photos of microstructures of the examined cast iron after different variants of heat treatment, a-f) lower magnification, g-l) double magnification

All images of the structures shown in **Figure 3** were subjected to computer analysis, and the following effects were observed: changes in the relative volume of austenite, changes in the length of ferrite needles.

3.2. Computer image analysis

The measurements were made using a MetIlo software image analysis, which is particularly dedicated to quantitative image analysis of the microstructure of materials [6]. Measurements of the volume fraction of austenite Vv were performed on 3-4 microstructure images for each variant of the heat treatment. Image preparation for automatic measurements included the use of a medium grey filter and automatic binarization by the method of K-means. In some cases, the shade correction and manual setting of the threshold grey level were necessary. The results are presented under Section 4.1. Automatic measurement of the length of ferrite needles has proved to be impossible because of the difficulty in separating the individual needles. Therefore, measurements were performed semi-automatically. In the specific area of each needle of the ferrite, a section line corresponding to its length was drawn in the MetIlo software. The lengths of the section lines were measured automatically. The results of measurements are presented under Section 4.2.

4. RESULTS OF RESEARCH

4.1. Changes in the relative volume fraction of austenite

The results of the austenite content measurements are presented numerically in **Table 3** and graphically in **Figure 4**. The content of austenite varies from 7.7 % (at 260 °C) to 20.3 % (at 400 °C). While the austenite content at 260 °C is very high (which should result in a high value of elongation), at a temperature of 400 °C, a higher value might be expected. From the graphs in **Figure 4** it can be concluded that the adopted austempering times of 90 and 120 minutes did not have a significant impact on the austenite content in cast iron matrix.

Table 3 Changes in the relative volume fraction of austenite as a function of the temperature of austempering.

T_{pi}, °C	τ_{pi}, min	Designation of HT variant	Vγ, %
260	120	W2	7.6
300	120	W4	8.6
330	120	W6	13.1
360	90	W8	13.9
380	90	W10	16.6
400	90	W12	20.5

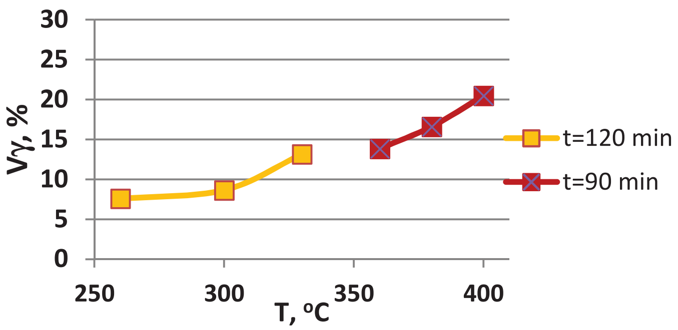


Figure 4 Plotted changes in the relative volume fraction of austenite as a function of the temperature of austempering

4.2. The effect of austempering parameters on the length of ferrite needles

Changes in the length of ferrite needles (L) are presented numerically in **Table 4** and graphically in **Figure 5**. From the data given in **Table 4** no obvious correlations between the length of the needles and austempering temperature can be derived. The longest needles (12.7 μm) were obtained at the austempering temperature of 330 °C, while the shortest (10.8 μm) - at 400 °C. To answer the question whether these values have any substantive justification, further tests of mechanical properties should be carried out.

Table 4 Changes in the length of ferrite needles as a function of the time and temperature of austempering

T_{pi}, °C	τ_{pi}, min	**Designation of HT variant**	**L, μm**
260	120	W2	11.2
300	120	W4	11.9
330	120	W6	12.7
360	90	W8	11.1
380	90	W10	11.5
400	90	W12	10.8

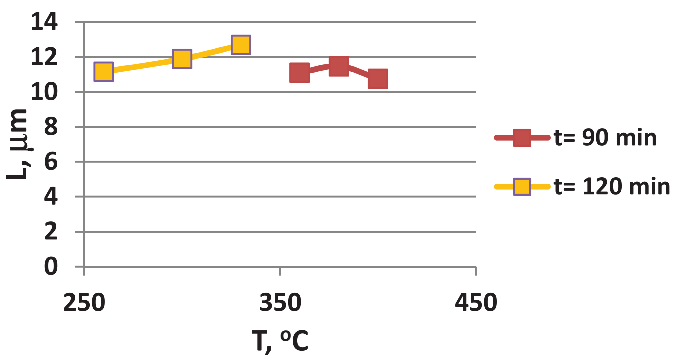


Figure 5 Plotted changes in the length of ferrite needles as a function of the time and temperature of austempering

5. SUMMARY

The tested ADI includes only one alloying element, i.e. nickel in the amount of 1.56 % (**Table 2**). This composition is quite unusual as normally cast irons of this type contain combinations of elements such as Ni, Mo, and Cu, occasionally also Mn and Cr, increasing their hardenability. In the technical literature there are no data on this type of cast iron. The content of other elements (C, Si, Mn, Mg, P, S) is typical for ductile iron.

The developed diagram of isothermal transformation allows selecting the austempering treatment parameters producing the required structure of cast iron, which in turn allows obtaining the required mechanical properties.

In this study, two ranges of the austempering treatment were adopted, i.e. 260 to 330 °C to obtain the lower ausferrite, and 360 to 400 °C to obtain the upper ausferrite. It is the fact well-known that these two types of ausferrite vary considerably as regards both the austenite content and the type of "needles" of the ferrite plates, thus having a direct impact on the cast iron properties. The higher is the content of austenite, the better is the cast iron toughness and vice versa, the lower is the content of austenite, the finer are the "needles" of ferrite, and the higher is the strength and hardness.

6. CONCLUSION

The object of the study was the austempered cast iron (ADI) containing only the addition of nickel in an amount of 1.56 %. For this cast iron a TTT diagram was developed. This composition of ductile iron is quite unusual, since ausferritic grades in most cases contain the combinations of nickel, molybdenum and copper added to increase the hardenability. Studies were carried out for two ranges of the isothermal transformation, i.e. for the lower range of 260 - 330 °C, within which the lower ausferrite is formed, and for the upper range of 360 - 400 °C, within which the upper ausferrite is formed. Visual evaluation of structures was done using a common microscope and a Metilo computer image analysis software, where the austenite content and the length of the “needles” of the ferrite plates were examined. The following was reported: austenite content increasing with the increasing temperature of austempering, the dimensions of ferrite "needles" increasing with the increasing temperature of austempering. These phenomena are typical for the ADI cast iron manufactured using more than one alloying element. The application in the ADI production of one alloying element only would enable cutting down the costs of such production. Studies should continue in this direction, extending the range of nickel content, and using for example 1.0; 1.5; 2.0 addition. At the same time the mechanical properties of the resultant ADI should be tested.

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