

## THE INFLUENCE OF PARAMETERS OF HEAT TREATMENT ON THE MICROSTRUCTURE AND STRENGTH PROPERTIES OF THE ADI AND THE AVGI IRONS

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### Abstract

The paper presents the results of investigation concerning the strength properties of the vermicular and the nodular cast iron both in the as-cast state and after the heat treatment held according to a couple of various options. The nodular cast iron exhibited almost 100% nodular graphite precipitates and the purely pearlitic matrix. The graphite precipitates in the vermicular cast iron were almost 100% vermicular ones, embedded in the pearlitic-ferritic matrix (50%/50%). The heat treatment of the examined cast iron types differed with respect to the temperature. The austenitization process was performed either at 900°C or at 960°C, while austempering was held either at 290°C or at 390°C. Both the austenitizing and the austempering time was constant and set to 90 min. Both the as-cast specimens and the heat-treated ones were subjected to mechanical testing which allowed to determine their properties, namely Rm, Rp0,2, A5, and hardness. The change of the initial matrix to the ausferritic one resulted in the increase in mechanical properties, however the results were diversified depending on the type of graphite precipitates occurring in the material.

**Keywords:** Nodular cast iron, vermicular cast iron, austempering, AVGI, ADI

### 1. INTRODUCTION

The strength of the nodular cast iron can be enhanced by subjecting the material to austempering process. The proper selection of the heat treatment parameters allow to produce cast iron exhibiting distinctly higher strength and functional properties than the initial, thermally not treated material.

ADI (Austempered Ductile Iron) is a material well known to manufacturers, but there is an unceasing tendency to improve the material and to get the knowledge of mechanisms which allow to increase its properties.

Besides the nodular cast iron, also the vermicular one is an attractive material for the foundry industry. The properties of vermicular cast iron locate this material between the grey and the nodular cast iron types [1]. Admittedly, the alloy is characterised by lower mechanical properties than the nodular cast iron (although it surpasses the grey iron with flake graphite in this respect), but it has in turn distinctly greater heat conductivity and damping capacity than the cast iron with nodular graphite. This leads to the great interest in this material, especially from the automotive industry [2]. An exemplary application can be the 3.0 TDI engine block (produced by Audi Company) made of vermicular cast iron [3]. It can be mentioned that the grey cast iron formerly commonly used for engine hulls is less rigid and exhibits lower fatigue resistance than the vermicular cast iron. Therefore the use of vermicular cast iron allows to reduce the wall thickness of castings, by the same reducing the mass of the entire individual casting even by about 20% [4].

The advantageous properties, which the nodular cast iron gained due to the austempering process transforming it into the ADI, were the reason for applying the same type of heat treatment to the vermicular cast iron.

## 2. AUTHOR'S INVESTIGATIONS

The nodular and the vermicular cast iron produced by one of the domestic foundries was used for the purpose of investigation. Test coupons of the IIb type were produced (in accordance with [5]). The test part of the mentioned test coupons was the material of which the tensile specimens were cut out. After measuring the strength properties, the specimens intended for metallographic examination were cut out of the end tabs of the tensile specimens.

Chemical compositions of the examined cast iron types, both nodular and vermicular, are presented in **Table 1**.

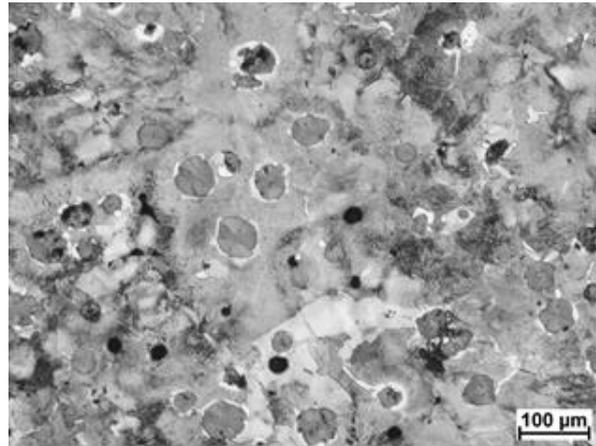
**Table 1** Chemical composition of the nodular and the vermicular cast iron

Chemical composition (%)							Sc*
C	Si	Mn	Cu	P	S	Mg	
Nodular cast iron							
3.57	2.33	0.38	0.55	0.061	0.008	0.062	0.9
Vermicular cast iron							
3.22	2.38	0.192	1.02	0.054	0.022	0.027	0.9
* the eutectic saturation degree Sc							

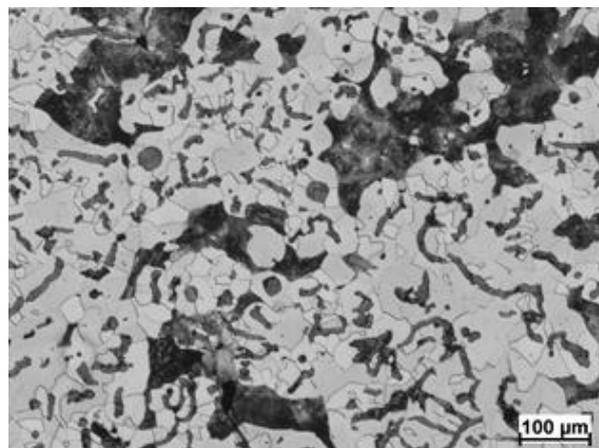
The metallographic examinations were performed by the methods of optical microscopy, using the Nikon Eclips optical microscope. Classification of graphite precipitates was performed for the non-etched specimens according to the Standard [6]. The microstructures were assessed in accordance with the Standard [7]. **Table 2** juxtaposes the results of examinations for the as-cast material of both examined types.

**Table 2** Quantities of pearlite and ferrite along with graphite characteristics in the examined cast iron

Cast iron type	Assessment of graphite precipitates [6]	Microsection area occupied by pearlite and ferrite [7]
Nodular	95% VI 4/5 + 5% V 4/5	P95 Fe05
Vermicular	95% III 4/5 + 5% VI 5/6	P50 Fe50



**Figure 1** Microstructure of the nodular cast iron etched with Nital, magn. 100×



**Figure 2** Microstructure of the vermicular cast iron etched with Nital, magn. 100×

Microstructures of the examined alloys are presented in **Figures 1** and **2**.

The data given in **Table 2**, as well as **Figures 1** and **2**, indicate that the examined vermicular cast iron contained over 95% of vermicular graphite precipitates, and about 5% of nodular graphite. The alloy exhibited the pearlitic-ferritic matrix, as was initially assumed, and the contribution of each of these phases was equal to approximately 50%. The nodular cast iron contained mainly nodular graphite (95%), and the matrix was pearlitic.

The examined cast iron types were subjected to the thermal treatment consisting in austempering. Taking up the suggestion resulting from initial examinations and the thermal treatment reported by some authors with respect either to the nodular cast iron [8-11] or to the vermicular one [12], it was assumed that the austenitization would be held at the temperature equal to either 900°C or 960°C, and the quenching at the temperature of either 290°C or 390°C. The difference in the latter temperature values equal to 100°C was applied in order to achieve structures with greater or lesser fractions of ferrite and austenite. The alternative sets of parameters applied during the heat treatment, denoted as 1 to 4, are presented in **Table 3**. Both the austenitization time and the austempering time were constant and equal to 90 min.

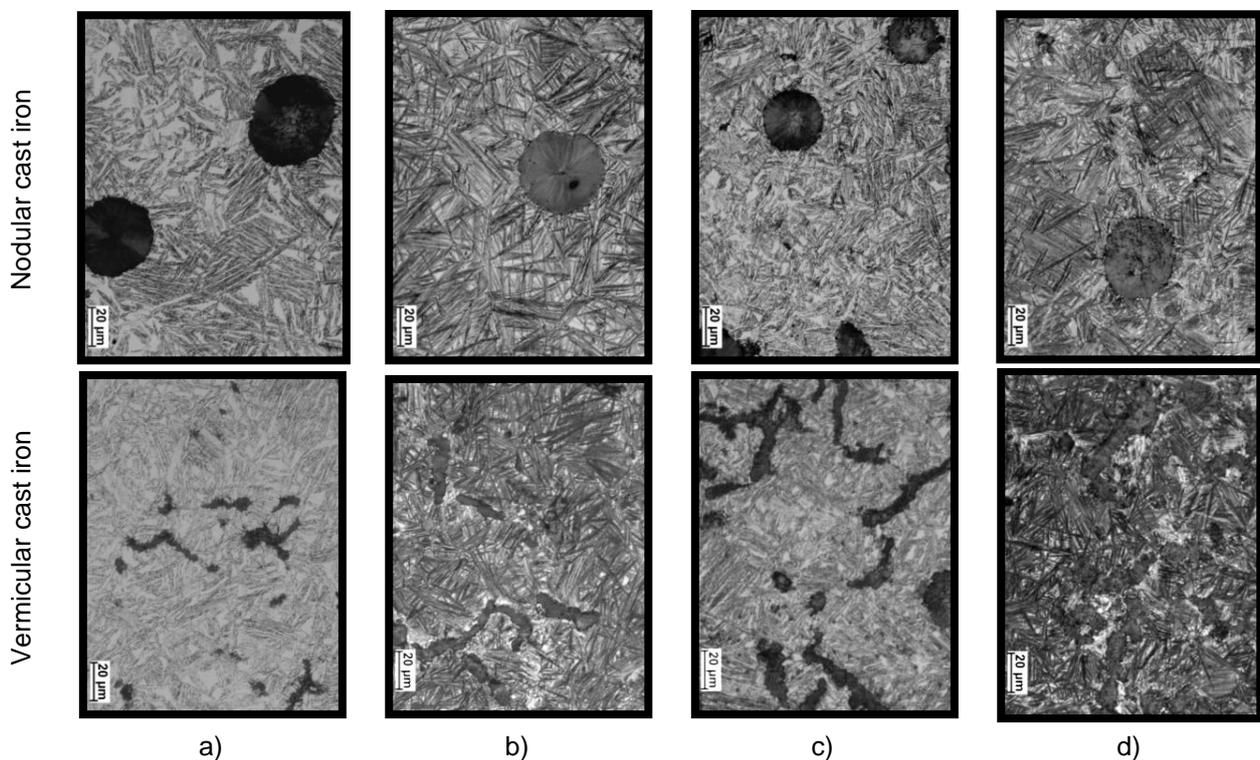
The tensile specimens were cut out of the test part of the cast coupons of the IIb type. The specimens intended for the further heat treatment had intentionally increased their initial thicknesses to compensate the possible scaling during the austenitization process. This allowance was removed after the heat treatment.

The heat treatment was performed at the research stand situated at Odlewnie Polskie S.A. enterprise in Starachowice. Austenitization was held in an air atmosphere using the resistance chamber furnace made by 'ELTERMA' Company. Austempering was performed in a quenching tank, in a salt bath used as the quenching agent. After taking the specimens out of the tank, the salt residues were washed off.

**Table 3** Parameters of heat treatment applied to the cast iron

Designation of heat treatment option	Temperature of austenitization $T_{\gamma}$ (°C)	Temperature of austempering $T_{pi}$ (°C)
Option 1	960	390
Option 2	960	290
Option 3	900	390
Option 4	900	290

**Figure 3** presents the microstructure of the examined alloys after the heat treatment according to the four specified options.



**Figure 3** Microstructures of nodular and vermicular cast iron after the heat treatment according to the option:

- a) No. 1 ( $T_{\gamma}=960^{\circ}\text{C}$ ,  $T_{pi}=390^{\circ}\text{C}$ ); b) No. 2 ( $T_{\gamma}=960^{\circ}\text{C}$ ,  $T_{pi}=290^{\circ}\text{C}$ ); c) No. 3 ( $T_{\gamma}=900^{\circ}\text{C}$ ,  $T_{pi}=390^{\circ}\text{C}$ );  
d) No. 4 ( $T_{\gamma}=900^{\circ}\text{C}$ ,  $T_{pi}=290^{\circ}\text{C}$ )

The strength properties were examined by means of the ZWICK 1488 tester. Hardness of the materials was checked by means of the Brinell hardness tester with a ball of 2.5 mm diameter under the load of 1,839 N. **Tables 4** and **5** give the average values of  $R_m$ ,  $R_{0.2}$ ,  $A_5$ , and the hardness of both the nodular and the vermicular cast iron, both in the as-cast state and after the heat treatment. For each type of the examined cast iron and for each option of the heat treatment as well as for the as-cast state, the average values of  $R_m$ ,  $R_{0.2}$ ,  $A_5$ , were calculated from measurements taken from four specimens. As to the average hardness, its values

were calculated from twelve measurements carried out for each cast iron type in every state (i.e. for the as-cast specimens and the heat-treated specimens of every option).

**Table 4** Average values of the tensile strength  $R_m$ , yield strength  $R_{0.2}$ , elongation  $A_5$ , and the hardness of the nodular cast iron before and after the heat treatment

State of the examined cast iron		Strength properties			
		$R_m$ (MPa)	$R_{p0.2}$ (MPa)	$A_5$ (%)	HB
As-cast		590	424	2.2	255
Heat-treated according to option*	1	829	583	4.4	283
	2	1,346	920	1.5	407
	3	979	592	6.5	299
	4	1,539	953	2.2	436

\* heat treatment parameters given in **Table 3**

**Table 5** Average values of the tensile strength  $R_m$ , yield strength  $R_{0.2}$ , elongation  $A_5$ , and the hardness of the vermicular cast iron before and after the heat treatment

State of the examined cast iron		Strength properties			
		$R_m$ (MPa)	$R_{p0.2}$ (MPa)	$A_5$ (%)	HB
As-cast		371	331	2.1	183
Heat-treated according to option*		623	485	1.6	260
		824	584	0.7	334
		616	492	1.0	280
		954	808	0.4	352

\* heat treatment parameters given in **Table 3**

### 3. CONCLUSION

The paper is focused on the mechanical properties of the ADI and AVGI cast irons, particularly on the dependence between their properties and the temperature of both the austenitization and the austempering processes. The work discusses two variable parameters of heat treatment, namely the austenitization temperature, which was set to be either 900°C or 960°C, and the austempering temperature, which was selected as either 290°C or 390°C, so that four options of thermal treatment were eventually considered (see **Table 3**).

It results from the observation of microstructures shown in **Figure 3** that both the nodular and the vermicular cast iron types subjected to the heat treatment are characterised by the ausferritic matrix, consisting of the acicular ferrite and austenite supersaturated with carbon. It can be seen that the area fraction occupied by individual phases depends on the temperature of austempering. The matrix was analysed by a computer program in order to find the fraction of the residual austenite. The results indicated that the largest fraction of the residual austenite in the matrix occurred in specimens austempered at 390°C (treatment options 1 and 3). The specimens austempered at 290°C (treatment options 2 and 4) were characterised by lower fraction of the residual austenite.

The data gathered in **Tables 4** and **5** prove that the highest tensile strength and yield strength values occurred for both the nodular and the vermicular cast iron thermally treated according to the options 2 or 4. The lower temperature of austempering (290°C) resulted in the increased tensile strength and yield strength. The highest values of  $R_m$  and  $R_{0.2}$  for vermicular cast iron (954 MPa and 808 MPa, respectively) and for nodular cast iron

(1,539 MPa and 953 MPa, respectively) were achieved after the heat treatment held in accordance with the option 4. It should be noticed that the austenitization temperature influenced the values of  $R_m$  and  $R_{0.2}$ . The higher austenitization temperature ( $960^\circ$  for the examined case) resulted in the tensile strength reduced by about 13%.

An increase in the temperature of austempering from  $290^\circ\text{C}$  to  $390^\circ\text{C}$  lead to the distinct increase of elongation.

The differences in mechanical properties of cast iron types thermally treated according to various options were related to different percentage of ferrite and austenite occurring in the matrices of examined materials. There was observed a tendency towards the increased ferrite fraction in the matrix, and by the same the reduced austenite fraction, for the increased austempering temperature. The greater ferrite content in the matrix resulted in an increase in plastic properties of the cast iron due to ferrite plasticity, at the cost of decreased tensile strength.

Considering the hardness of the examined as-cast vermicular cast iron, it can be stated that it was lower than the hardness of the nodular cast iron. This is related to the respectively large ferrite percentage in the matrix, which amounted to 50%. The hardness of the examined materials after the heat treatment depended on the applied parameters of the treatment, particularly on the austempering temperature  $T_{pi}$ . The higher the  $T_{pi}$  temperature, the lower was the resulting hardness of the examined cast iron.

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