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# Effect of Heat Treatment Parameters on the Toughness of Unalloyed Ausferritic Ductile Iron

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## Abstract

Studies were carried out to determine the effect of heat treatment parameters on the plastic properties of unalloyed ausferritic ductile iron, such as the elongation and toughness at ambient temperature and at  $-60\text{ }^{\circ}\text{C}$ . The effect of austenitizing temperature (850, 900 and  $950\text{ }^{\circ}\text{C}$ ) and ausferritizing time (5 - 180 min.) at a temperature of  $360\text{ }^{\circ}\text{C}$  was also discussed. The next step covered investigations of a relationship that is believed to exist between the temperature (270, 300, 330, 360 and  $390\text{ }^{\circ}\text{C}$ ) and time (5, 10, 30, 60, 90, 120, 150, 180, 240 min.) of the austempering treatment and the mechanical properties of unalloyed ausferritic ductile iron, when the austenitizing temperature is  $950\text{ }^{\circ}\text{C}$ . The “process window” was calculated for the ADI characterized by high toughness corresponding to the EN-GJS-800-10-RT and EN-GJS-900-8 grades according to EN-PN 1564 and to other high-strength grades included in this standard. Low-alloyed cast iron with the nodular graphite is an excellent starting material for the technological design of all the ausferritic ductile iron grades included in the PN-EN-1624 standard. The examined cast iron is characterized by high mechanical properties stable within the entire range of heat treatment parameters.

**Keywords:** ADI, toughness, ausferrite, mechanical properties

## 1. Introduction

To make high-quality ADI castings, the following process parameters have to be carefully selected:

- casting; gating system, and time and temperature of pouring,
- metallurgy: metallurgical quality, chemical composition, melting, spheroidization and inoculation,
- heat treatment; temperature and time of austenitizing and ausferritizing.

Thin-walled castings do not require alloying elements (Ni, Cu, Mo) to improve the hardenability. The austenitizing temperature is selected from the range of 850 to  $950\text{ }^{\circ}\text{C}$ , while the time of annealing depends on the casting wall thickness and

complexity. During heat treatment, the austenite is saturated to maximum with carbon from the pearlite and partially also from graphite. In the process of austempering, the primary austenite ( $\gamma_0$ ) is transformed into the saturated plates of ferrite ( $\alpha$ ) and high carbon austenite ( $\gamma_{\text{HC}}$ ). Further annealing results in a decomposition of the high-carbon austenite into ferrite and carbides. This process is shown in Figure 1 [1, 2].

The selection of heat treatment parameters is based on the calculated values of the process window giving a maximum content of austenite in the structure of ausferritic ductile iron. Changes in the amount of retained austenite in the cast iron structure are inherently related with the heat treatment parameters (Fig. 2) [2, 3]. Exceeding certain temperature and/or time limits

leads to a dramatic decrease of the austenite content in cast iron due to its decomposition (stage II).

The right choice of the process window parameters for a particular grade of the ausferritic ductile iron provides castings with optimal mechanical and plastic properties. However, studies

of the effect of the ausferritizing temperature (250-420 °C) on the mechanical properties of cast iron when the time is kept constant (1 hr) do not give a full picture of the process window [4]. An example of broader studies is analysis of the effect of both

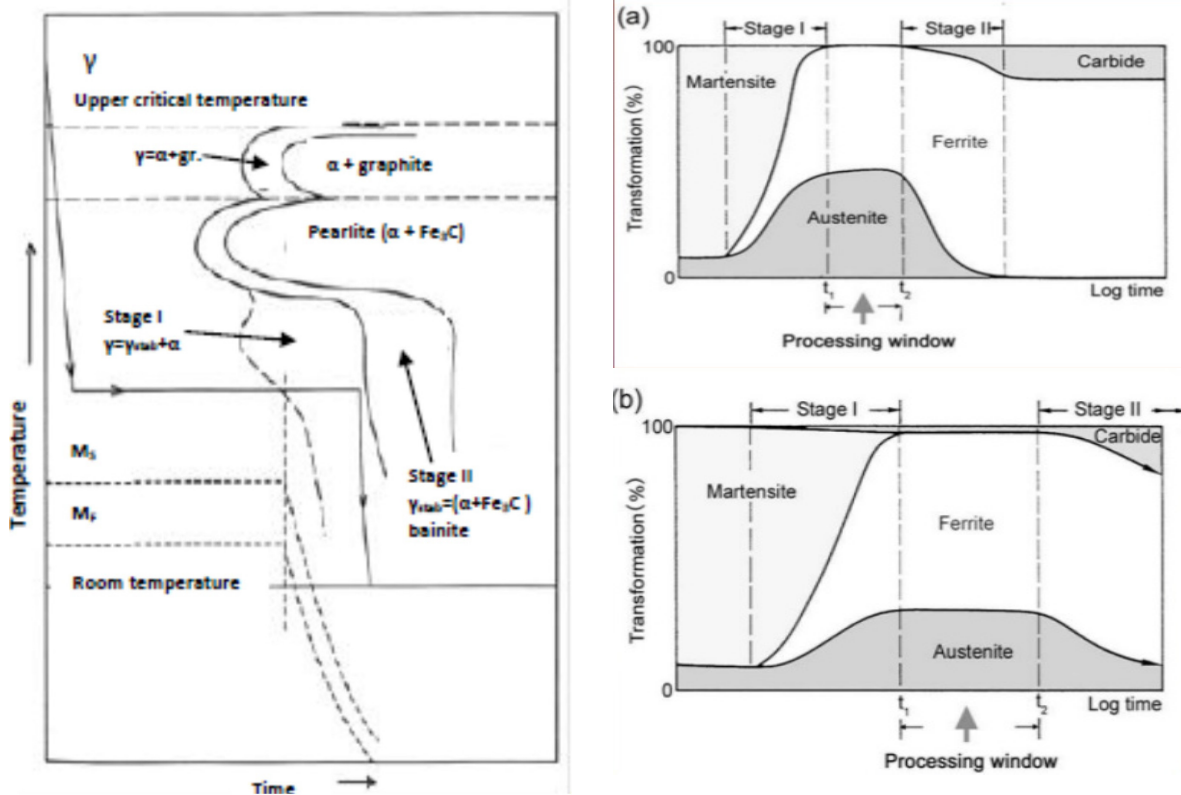


Fig. 1. Flowchart of the isothermal transformation: a) at high temperature, b) at low temperature [1, 2]

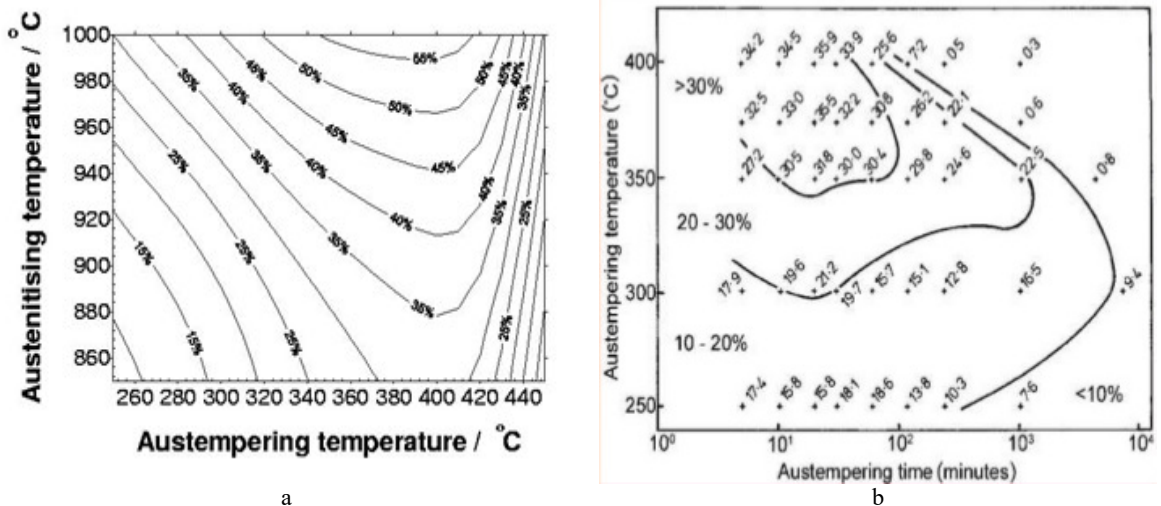


Fig. 2. Austenite content in cast iron as a function of: a) austenitizing and ausferritizing temperature (time 2h), b) ausferritizing temperature and time (cast iron with 1% Ni) [2, 3]

temperature (300-400°C) and time (1 - 4 hrs) of ausferritizing [5]; the process window indicated in these studies is 350°C and 2 hrs.

Particularly sensitive to changes in the time of the ausferritizing treatment under isothermal conditions are the plastic properties of

cast iron (elongation and toughness). In the ausferritic ductile iron these parameters can reach high values and are particularly appreciated by designers. The functional properties of ADI, as well as some economic aspects of its technology decide about the competitiveness of this engineering material compared to the cast steel, forged steel and/or aluminium alloys (the problem of conversion) [6, 7].

The authors of [8] applied Mössbauer spectroscopy to the quantitative assessment of structural constituents in the ausferritic ductile iron. Figure 3 shows the content in the cast iron structure of ferrite from the first ( $\alpha_1$ ) and the second ( $\alpha_2$ ) stage of the ausferritizing treatment, and also the content of austenite and carbides in the case of ausferritization carried out at 900°C for

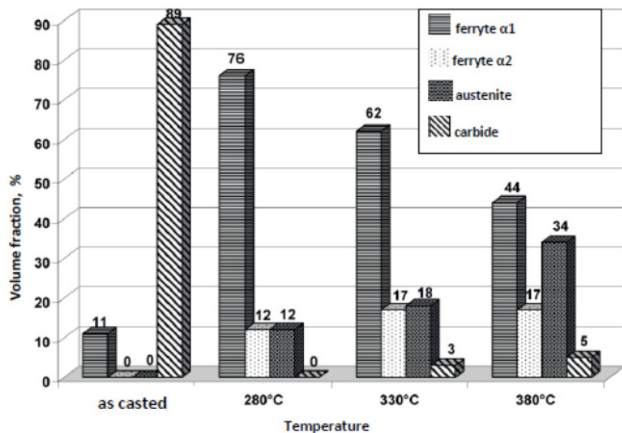


Fig. 3. Austempering temperature vs metal matrix composition [8]

2 hrs. Yet, the presented results are still insufficient to claim that the process window has been adequately selected for this cast iron grade. Physical metallurgy confirms the active role of graphite in the heat treatment process. It has been found that the cast iron after heat treatment contains less graphite than the base material (Fig. 4) [9]

## 2. Methodology

Samples for tests were taken from the production melts of unalloyed ductile iron, grade EN-JS-500-7 according to EN-PN-1563. This material was used as a base cast iron heat treated next to obtain ADI. The samples were taken in accordance with the procedure described under item 8.2 of EN 1564. They were prepared for mechanical tests (tensile strength and unnotched impact strength) following guidelines given under item 9 of the same standard. The heat treatment was performed in an electric chamber furnace (austenitizing) and in an electric furnace with salt bath (ausferritizing).

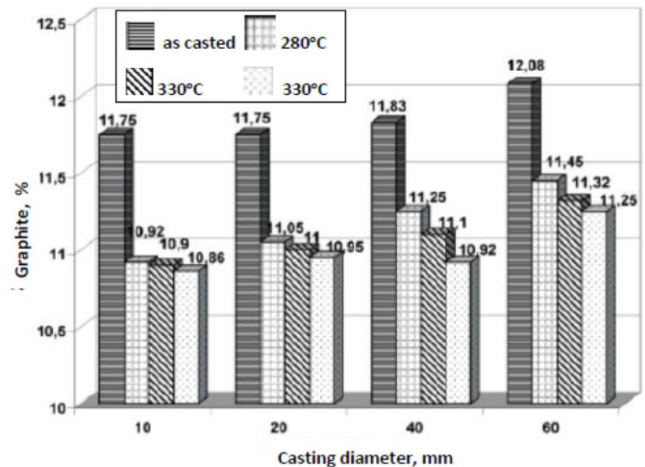


Fig. 4. Austempering temperature vs graphite content in casting with varying wall thicknesses [9]

The study comprised two stages. The first stage was devoted to the investigation of the effect of austenitizing temperature (850, 900 and 950°C) on the mechanical and plastic properties, with attention focused more on the plastic properties of cast iron. Austempering was carried out at 360 °C with the holding time of 5, 10, 30, 60, 120, and 180 minutes. In the second stage of studies, the austenitizing temperature of 950 °C, considered optimal for the plastic properties of cast iron, was selected. The time of austenitizing was established at 2 hours. Austempering was carried out at temperatures of 270, 300, 330, 360 and 390 °C for the time of 5, 10, 30, 60, 90, 120, 150, 180 and 240 minutes. This regime of the austempering treatment, carried out at different levels of time and temperature, was based on the literature data predicting dynamic changes taking place in the austenite as a function of the heat treatment time and temperature (cf. Fig. 2 [2, 3]). Different values of the ausferritizing temperature were selected to test in the experiment the possibility of obtaining different grades of ADI.

The tensile test was carried out in a Zwick Z250 machine, while impact strength was tested at ambient temperature and at -60 °C using a hammer of 300 J energy.

## 3. Test results

The results of the first stage of the studies devoted to the cast iron plastic properties are shown in Figure 5. Based on the obtained results, a thesis was put forward that the austenitizing temperature of 950 °C allows obtaining a broad and safe process window and achieving stable plastic properties in castings made from the unalloyed ductile iron.

The results of the second stage of studies are summarized in Figures 6 - 9. Plastic properties of the cast iron which are of particular interest to the engineers include the elongation and toughness at ambient and low temperatures. A high dynamics of changes in the value of ductility depending on the time of austempering has been reported, especially at 390 and 360 °C. High temperatures accelerate the transformation of austenite. The process least stable in time is the ausferritizing treatment carried

out at 390 °C. For the values of A and K this is the narrowest process window. The parameter least sensitive to the time of the

ausferritizing treatment is the ultimate tensile strength UTS (Fig. 9).

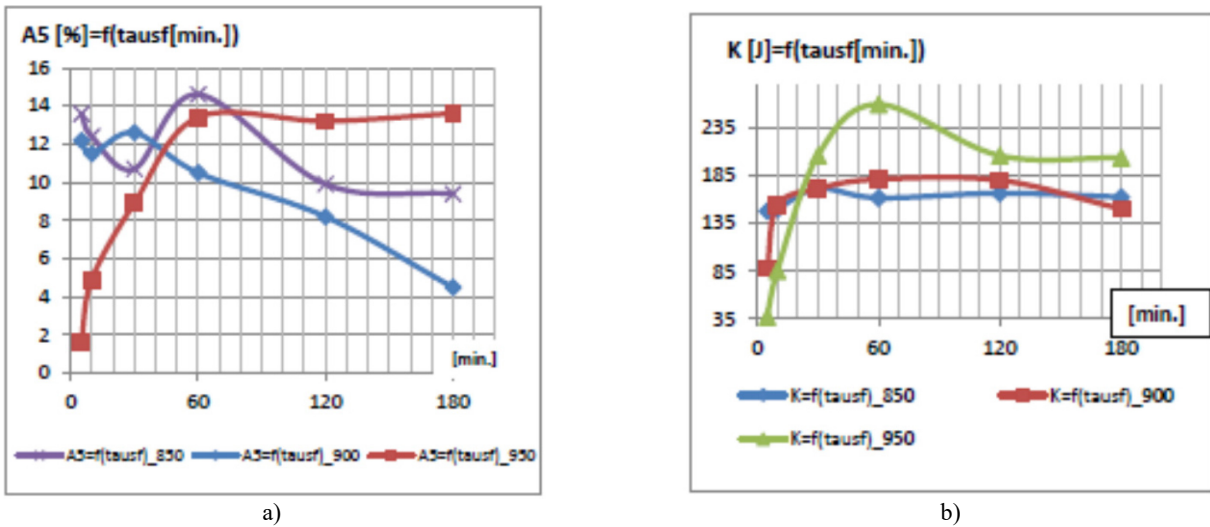


Fig. 5. The effect of austenizing temperature and ausferritizing time ( $T = 360^{\circ}\text{C}$ ) on the elongation (a) and impact strength (b) of cast iron

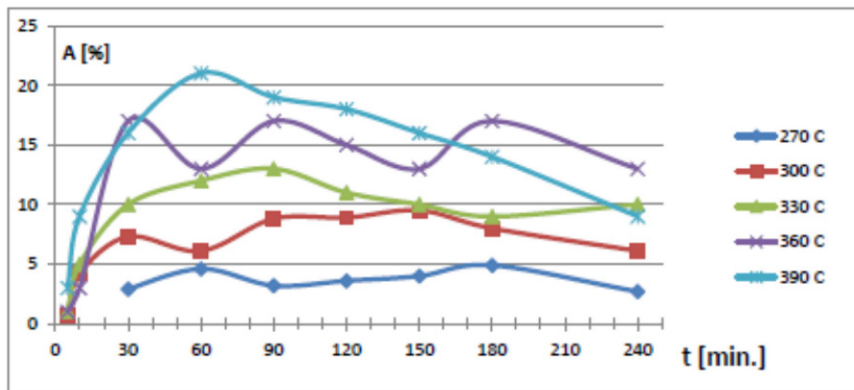


Fig. 6. Ausferritizing time and temperature vs ADI elongation  $A$

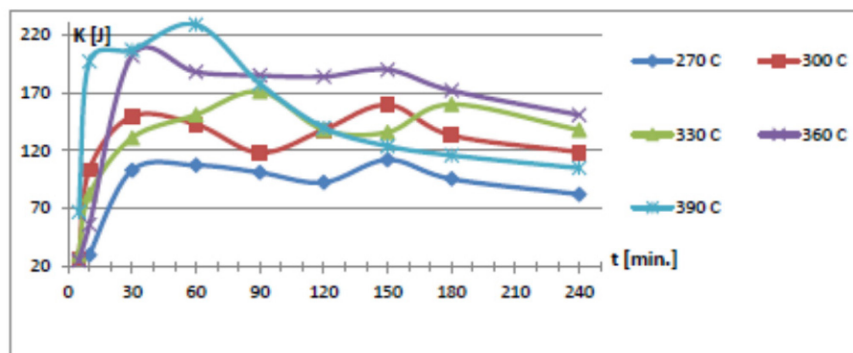


Fig. 7. Ausferritizing time and temperature vs ADI impact strength  $K$  at ambient temperature

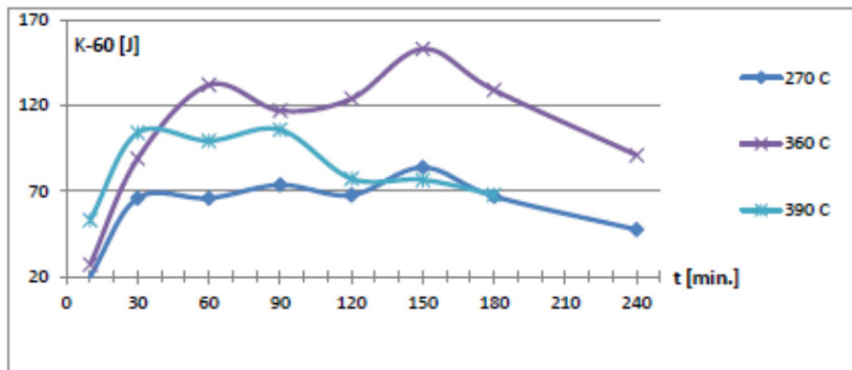


Fig. 8. Ausferritizing time and temperature vs ADI impact strength K at  $-60^{\circ}\text{C}$

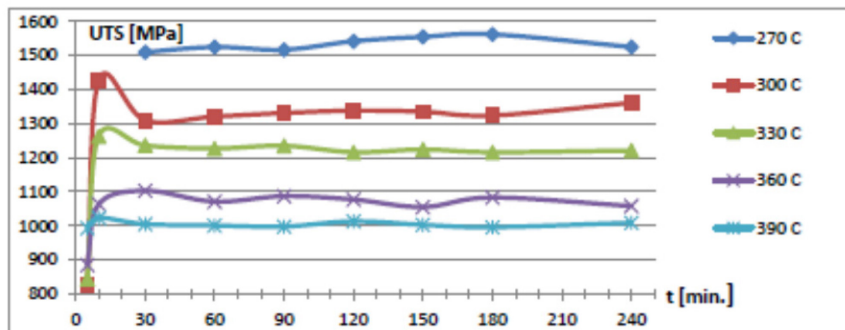


Fig. 9. Ausferritizing time and temperature vs ADI ultimate tensile strength UTS

## 4. Summary

The conducted studies have led to the following conclusions:

1. Unalloyed ductile iron is a good starting material for the production of thin-walled ADI castings.
2. Higher values of the austenitizing temperature ( $950^{\circ}\text{C}$ ) affect in a positive manner the cast iron ductility and provide a wider process window for the austempering treatment.
3. High-temperature austenitizing process promotes high content of the retained austenite in ausferrite (cf. Fig. 2a, [2]). The unalloyed ausferritic ductile iron with high plastic properties has a wide process window for the austempering treatment. The recommended temperature is  $360^{\circ}\text{C}$  with the time of holding castings in a salt bath amounting to 1-2 hours.
4. The time of holding castings in a salt bath significantly affects the dynamic changes in all the tested plastic properties. The background for these changes appears to be the reaction kinetics responsible for the formation of high-carbon austenite (Stage I) and its subsequent decomposition (Stage II). The cyclic changes in the plastic properties assuming the shape of sine curves are similar to changes in the content of austenite in ausferrite (cf. Fig. 2a [3]).
5. Low-alloyed cast iron with the nodular graphite is an excellent starting material for the technological design of all the ausferritic ductile iron grades included in the PN-EN-

1624 standard. The examined cast iron is characterized by high mechanical properties stable within the entire range of heat treatment parameters (cf. Fig. 9).

6. The mechanism of changes which occur during the ADI heat treatment can be explained very precisely with the use of Mössbauer spectroscopy, which successfully assists the quantitative determination of structural constituents present in ADI.

## Acknowledgements

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