# Measurement of Phase Transformation Kinetics in Austempered Ductile Iron

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## Abstract

The kinetics reaction occurring during the austempering treatment of ductile iron containing different concentration of Cu and Ni was studied. The samples were subjected to heat treatment in dilatometry equipment. In addition to that Vickers hardness measurements and metallographic investigations were performed. The exponential equation was used to describe the isothermal transformation processes. The dilatometric studies indicate that the addition of copper in contrast to the addition of copper and nickel does not significantly affect incubation time of austempering transformation. It has been shown that austermpering process is characterized by different transformation rate. In the initial range the addition of copper, and even in a greater extent both copper and nickel reduces its rate and moves the maximum value of the right. Results of this study also indicate that the initial growth of plates of ferrite occurs mainly diffusionlessly and the resulting maximum on the transformation rate curve should be identified with the time after which predominantly ferrite plates growth by diffusion.

**Keywords**: austempered ductile iron; phase transformation; dilatometry.

## 1. Introduction

Austempered ductile iron (ADI) is a heat treated ductile iron which combines unique mechanical properties (high strength, good ductility and toughness) with the relatively low production costs and weight saving potential of a cast material [1]. ADI offers an alternative to steel and aluminum alloys and can be used in diverse applications: eg. automotive and agricultural industries [1–4]. Heat treatment parameters used in ADI production are strongly influenced by the alloying elements additions. Moreover microstructure parameters like eg. austenite fraction and carbon content of the austenite varied by heat treatment parameters such as austenitising temperature and time and also austempering temperature and time.

For the analysis of the austempering kinetics a dilatometric study can be used [1-4]. It represent relative sample expansion of the material subjected to investigation as a function of time and temperature. The exponential equation is used to describe the isothermal transformation processes:

$$f = exp\ (-1/nt) \qquad (1)$$

where: $f$ – volume fraction of the transformation product, $n$ is curve shaped constant under a given transformation condition.

In commercial practice, nickel (up to 2.0%) and copper (up to 1.5%), are common alloying elements in high strength austempered ductile irons to enhance hardenability and ductility. Both nickel and copper are fcc metals and are highly soluble in austenite. Sufficient alloying additions usually provide adequate austemperability but their presence can also influence the austempering kinetics leading to a change in mechanical properties. The aim of the present investigation is to follow the austempering of ductile cast iron

alloyed by Cu and by Cu and Ni by dilatometric study helping to deepen the knowledge of transformation kinetics in ADI.

## 2. Experimental

The experimental melts were done in an electric induction furnace of intermediate frequency in a 15 kg capacity crucible. The furnace charge consisted of the following materials: Sorelmetal, technically pure silica, Fe-Mn, steel scrap, copper and nickel. After metal heating to a temperature of 1490 ºC, the bath was held for 2 min and then, the spheroidization and modification operations were performed by a bell method. For the spheroidization, the foundry alloy Fe-Si-Mg (6% Mg) in an amount of 1.5 wt.% was used, while the inoculation was done by means of the Foundrysil inoculant in an amount of 0.5 wt.%. The pouring temperature was 1400 ºC. The cast iron was poured into Y block (13 mm) ingots according to ASTM A 536-84. Three heats were performed with additives of Cu and both Cu+Ni. Chemical composition of the investigated ductile iron is summarized in Table 1.

The heat treating procedures were as follows: (1) austenitizing at 900 ºC for 30 minutes, (2) austempering at 380 ºC for 2 hour, (3) air cooling to room temperature. The austempering was performed in a salt bath furnace.

The dilatometric studies were performed using the DI-105 absolute dilatometer. Vickers hardness measurements were made in a HPO-250 hardness tester. Moreover metallographic characterization was made using a Leica MEF 4M microscope and QWin v3.5 quantitative analyzer at various magnifications to observe graphite morphology and matrix.

## 3. Results and Discussion

Figure 1a shows dilatometry curves illustrating the degree of transformation (f) as a function of austempering time (t) of investigated alloys.

Figure 1b shows the transformation rate during austempering expressed as the first derivative with respect to time of f(t). Quantitative parameters describing the transformation kinetics of austempering are summarized in Table 2.

Metallographic examination as well as Vickers hardness measurements were performed for samples of alloys A, B and C, which were isothermally austempered for different times in a salt bath: a) time of transformation start, b) the time of the maximum transformation rate, c) the total austempering transformation time (Table 1). Results of hardness measurement are shown in Table 3, and the resulting images of microstructures, etched with a solution of nitric acid in ethanol are shown in Figures 2a, 2b and 2c, respectively.

The essence of the austempering transformation is the nucleation and the growth of ferrite plates in the metastable austenite during isothermal holding in the temperature range above the diffusionless martensitic transformation and below the diffusive transformation of the austenite into ferrite and austenite to pearlite. The transformation kinetics depends on the chemical composition of the base iron, shape and size of graphite and the austenitizing and austempering temperatures.

Table 1. Chemical composition of the investigated ductile iron

| Chemical composition | | | | | | | |
|---|---|---|---|---|---|---|---|
| No. of Alloy | C% | Si% | Mn% | P% | S% | Mg% | Cu% | Ni% |
| A | 3.64 | 2.70 | 0.39 | 0.03 | 0.01 | 0.040 | 0.01 | 0.03 |
| B | 3.65 | 2.65 | 0.30 | 0.03 | 0.01 | 0.045 | 0.99 | 0.04 |
| C | 3.61 | 2.70 | 0.40 | 0.03 | 0.01 | 0.050 | 0.95 | 1.10 |



a)                                                                                          b)
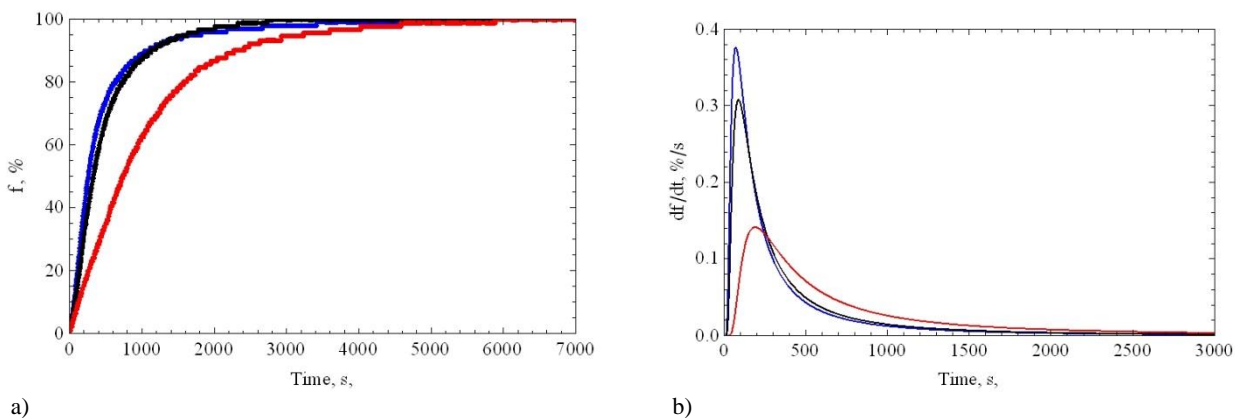
Fig. 1. Austempering transformation kinetics: a) degree of transformation, b) rate of a transformation. Curve: blue-alloy A, black -alloy B, red – alloy C

Table 2. Kinetics parameters of ausferritic transformation

| No. of Alloy | Incubation time, s | Austempering transformation time, s | Parameter n, ×10³ (eq. 1) | Max. transition rate, df/dt, %/s | Time of maximum. transition rate, s |
|---|---|---|---|---|---|
| A | 41 | 5535 | 6.94 | 0.37 | 70 |
| B | 43 | 2780 | 5.68 | 0.31 | 88 |
| C | 110 | 6000 | 2.61 | 0.14 | 192 |

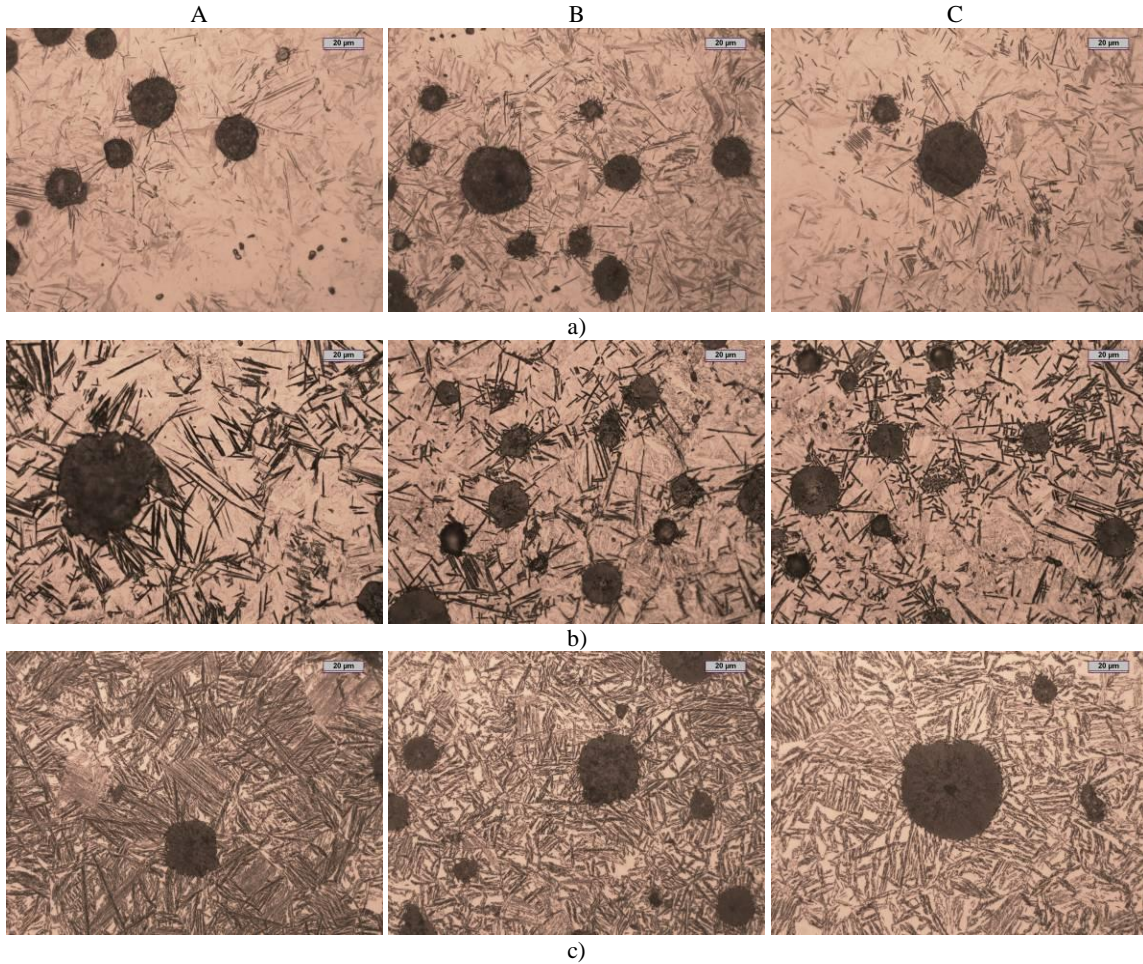|  A | B | C |
|---|---|---|



a)



b)



c)

Fig. 2. Microstructures of investigated alloys A, B and C: a) just after incubation time, b) at the time of maximum transition rate, c) at full austempering transformation time

Table 2. Results of the measurement of hardness (HV30) of A, B and C alloys after characteristic austempering times

| Sample no. | Austempering time, s | Hardness, HV30 |
|---|---|---|
| A | 70 | 670 |
|  | 111 | 575 |
|  | 5535 | 330 |
| B | 88 | 670 |
|  | 131 | 631 |
|  | 2780 | 331 |
| C | 192 | 657 |
|  | 302 | 572 |
|  | 6000 | 308 |

From dilatometric studies result that the addition of copper (alloy B) does not significantly affect incubation time contrary to copper and nickel (alloy C), which more than double extend the incubation time of austempering transformation. This result is confirmed by metallographic examinations (Fig. 2a) and the measurement of hardness of tested alloys (Table 3). Visible few ferrite plates on the background of martensitic matrix of A, B and C alloys indicate that the transformation is started. Slightly reduced hardness of the C alloy should be explained by the influence of nickel on the $M_s$ (martensite start) temperature, and hence with a smaller fraction of martensite. The phase components of the metallic matrix of A, B and C alloy, which microstructure is shown in the figure 2b is ferrite, martensite and unstable austenite. In the initial range the addition of copper, and even in a greater extent both copper and nickel reduces its rate and moves the maximum value of the right (Fig. 1b). It can therefore be concluded that in the first range of austempering transformation copper and nickel reduce its speed, making it difficult to create ferrite nucleus (longer time is required) and limiting its growth. This is clearly evidenced by the shorter ferrite plates in the microstructure of B and C alloys (Fig. 2b). Results of this study indicate that the initial growth of ferrite plates occurs mainly diffusionlessly. The resulting maximum on the transformation rate curve (Fig. 1b) should be identified with the time after which predominantly ferrite plates growth by diffusion, and its speed is determined by the diffusion of carbon in austenite. Transformation times determined by the dilatometric studies were used for A, B and C alloys and they microstructures are shown in Figure 2c. In a second range of austempering (from about 50% of transformation) the additive of copper increases the transformation rate thus significantly reduces its duration time. In the case of the addition of both copper and nickel the longest time was achieved at which the greatest impact has the lowest transformation rate in its initial range. The differences in the morphology of the ferrite plates as well as transformation rate in the second range allow to conclude that the addition of copper as opposed to copper and nickel increases its rate by facilitating the diffusion of carbon in austenite.

## 4. Conclusions

The dilatometric studies indicate that the addition of copper (alloy B) in contrast to the addition of copper and nickel (alloy C) does not significantly affect incubation time of austempering transformation. Austermpering process is characterized by different transformation rate in time (Fig. 1b). In the initial range the addition of copper, and even in a greater extent both copper and nickel reduces its rate and moves the maximum value of the right. Results of this study indicate that the initial growth of plates of ferrite occurs mainly diffusionlessly. The resulting maximum on the transformation rate curve (Fig. 1b) should be identified with the time after which predominantly ferrite plates growth by diffusion. In a second range of austempering (from about 50% of transformation) the additive of copper increases the transformation rate thus significantly reducing its duration time. In the case of the addition of both copper and nickel the longest time was achieved at which the greatest impact has the lowest transformation rate in its initial range.

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