DETERMINATION OF THE PROCESS WINDOW OF AUSTEMPER TREATMENT TO OBTAIN ADI THROUGH NEURAL NETWORK SIMULATION *

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Abstract

The objective of this work is to determine the process window of austemper treatment to obtain an Austempered Ductile Iron (ADI). A ductile iron alloy with additions of manganese, copper, nickel and molybdenum was used. The austemper cycle was consisted in austenitizing at 900°C for 90 minutes and austemper at 380°C with different times. To determine the process window, it was used a group of programs which allows, through neural network method, estimate the amount of retained austenite in function of the alloy composition and the austemper treatment cycle parameters. The results of the simulation were compared with experimental results of hardness and toughness tests. According to the simulations, the highest retained austenite content is reached through austemper performed for 35 to 40 minutes. The experimental results show hardness stabilization on austemper times of 60, 90 and 120 minutes. The neural network simulation was considered a good tool, permitting the cost reduction upon the necessary tests to determine the process window on an ADI development.

Keywords: Austempering Ductile Iron; Process Windows; Neural Network; Retained Austenite.

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1 INTRODUCTION

Metallic articles production, using foundry techniques remount to 5000 to 3000 years b.C., existing in China artifacts build with cast iron around 600 years b.C. Since then, this technique has been improved, with a large amount of applications, of components with a few grams, to components weighting tons [1]. A leap in cast iron application was given with the development of ductile cast iron, which patent of magnesium use to obtainment of graphite nodes was deposited in 1949. Therefore, it was no longer necessary the expensive maleabilization treatment to obtain a more tenacious and ductile cast iron [2]. Posteriorly, in the 70's, began the production of ductile iron items submitted to austemper treatment, which conceived improved mechanical properties to the alloy.

O Austempered Ductile Iron (ADI) has singular characteristics, resulted from the isothermal austemper treatment applied to the ductile cast iron. The performing of austemper provides improvements on the mechanical properties of the ductile iron, individually or combined, depending on the alloy composition and the parameters used on the heat treatment cycle. The changes on the mechanical properties on the ductile iron after an austemper cycle is due to the microstrutural modification, which goes from ferritic or perlitic to acicular ferrite and high carbon stable austenite [3, 4].

The austemper reaction occurs with the nucleation and growth of acicular ferrite through grain boundaries or graphite and carbon diffusion in the austenite simultaneously. The ferrite needles growth allows the increase of the carbon content on the remaining austenite. This step, exemplified in reaction (1), is the prime stage of the transformation which, when complete, confers the best properties combination to ADI.

$$1^{o}\text{ stage: } \gamma \rightarrow \alpha_{ac} + \gamma_{HC} \qquad (1)$$

$$2^{o}\text{ stage: } \gamma_{HC} \rightarrow Fe_3C + \alpha \qquad (2)$$

The higher content of high carbon austenite is obtained in the end of the first stage, reaching, thus, an increased index of thermal and mechanical stability. This stability occurs due to the high carbon content in the austenite solid solution, and it shows itself lower when the austemper is performed at low temperatures (260°C and 268ºC) in comparison when it is performed at high temperatures, such as 371°C, 385°C and 399ºC [5].

The time comprehended between the final of the first stage and the beginning of the second stage of the austemper reaction is denominated process window, where the percentage of retained austenite is highest, which results in an increase of the toughness. Remaining itself with the isothermal austemper treatment, it will occur the carbides precipitation and ferrite formation from the high carbon austenite. This is the second stage of the austemper reaction, which is undesired on ADI, because it leads to toughness and ductility decrease on the material. The process window depends greatly on the austenite chemical composition influence after the austenitizing stage, as well as the austemper temperature. As it can be seen in figure 1B, the increase on the manganese content decreases significantly the process window [6].

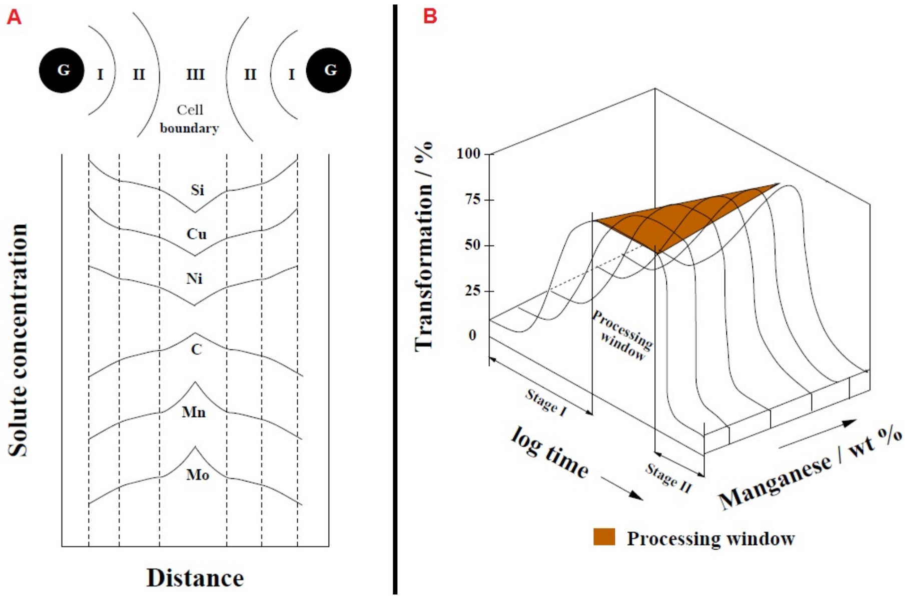

Figure 1. Segregation profile of different alloy elements on the ductile iron (A) and manganese influence on the austemper process window (B). Adapted from [6].

It is also necessary to consider the segregation of the elements dissolved in iron, because the transformation kinetics will present variations, mainly in regions of the part more susceptible to segregation occurrence. In figure 1A is possible to observe how the major alloys elements used in the production of ADI occur.

Austemper temperature and time are critical factors on the determination of the carbon content in solid solution on the austenite [7]. The increase of austenitizing temperature increases the carbon maximum content on the austenite. The higher carbon content on austenite reduces the acicular ferrite nucleation rate, reducing the velocity which reaction 1 takes place, fact that will result in a coarser structure on ADI and will not change the reaction 2 kinetics [8].

The development of a free access programs group allows the calculation of the estimate retained austenite as function of the alloy and the austemper cycle parameters [9]. The model developed by Yescas and Bhadeshia and the simulation software implemented by David Mackay, consider the C, Si, Mn, Cu, Ni and Mo contents present in the ductile cast iron alloy and the austemper cycle parameters, such as austenitizing temperature and time and the austemper temperature and time. The model and the simulation program work with a large database, composed by experimental results reports on the literature. [10]

The objective in this research is to compare the results obtained through the simulation method with experimental results and the variation of retained austenite percentage from the simulation with the results from the impact and hardness tests.

2 DEVELOPMENT

2.1 Experimental procedure

Ductile cast iron with predominantly perlitic matrix and adequate chemical composition to obtainment of high mechanical resistance ADI (Table 1) was used to machine 20 blocks, directly from the as-cast part.

Table 1. Ductile cast iron chemical composition. (%wt)

C	Si	Mn	Mg	Cu	Ni
3.56	2.30	0.32	0.034	0.66	0.53
Mo	**Sn**	**S**	**P**	**Cr**	**Fe**
0.18	0.02	0.007	0.021	0.03	Balance

The blocks were separated in five groups which were submitted to austemper treatment cycles, where only the austemper time was changed. The austenitizing was performed at 900°C for 90 minutes in a resistive furnace. The isothermal austemper treatment was performed in a Zamak 5 metallic bath, which attends the requisites to ADI obtainment [11], at the temperature of 380°C for 15, 30, 60, 90 and 120 minutes. Zamak 5 bath was kept in a silicon carbide crucible with 3.3 liters capacity and the temperature was maintained by a well type resistive furnace with an electronic temperature controller.

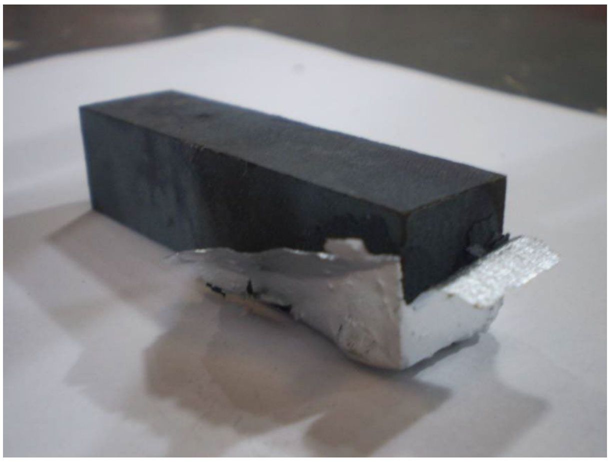

Figure 2. Cleanse of the austempered ductile cast iron.

After Austempering, the Zamac cover, which recovered total or partially the blocks, was removed, as it can be seen in figure 2. The impact specimens for Charpy tests were machined and its dimensions were 10x10x55 mm, according to ASTM E.23 standard. For each austemper cycle, as well for the as-cast material, four specimens were tested. To ADI evaluation, according to ASTM A 897M standard, a unnotched specimen was used.

In each specimen used on the impact tests it was performed, in random faces, hardness measurements. Brinell method was employed with 3000Kgf load for 15 seconds through the tungsten carbide sphere (diameter = 10mm).

2.2 Simulation

The parameters archive was set with the contents of, in weight, carbon, silicon, manganese, molybdenum, nickel and copper of the ductile iron. It was also informed the austenitizing temperature in Celcius, austenitizing time in minutes e austemper temperature in Celcius. The simulations were performed with different austemper times, from 5 to 145 minutes, with 5-minute increments. The program provides the estimated value of retained austenite and the error associated to the calculation, above or below.

2.3 Results and Discussion

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Table 2 shows the Charpy impact tests results and the hardness measurements. At austemper times of 15 and 30 minutes, it was observed a decrease on toughness when compared to the as-cast material. The austemper cycles of 60 and 90 minutes showed the higher values of average toughness and toughness in accordance with ASTM E.23 standard (which considers only the three highest values between the four tested specimens). Slight variation of hardness was observed after 60 minutes of austemper.

Table 2. Charpy test impact energy and average hardness for different austemper times.

t_A [min]	Toughness Average [J]	Standard Deviation	Toughness ASTM E.23 [J]	Standard Deviation	Hardness [HB]	Standard Deviation
Bruto	42.4	10.2	47	5.2	251	2.4
15	20.1	7.2	23	6.4	358	11.7
30	36.7	9	40	7	307	6.8
60	60.5	10.3	65	4.6	284	6
90	65.9	4.5	68	3.5	290	3.3
120	51.7	9.8	55	8.3	284	3

Analyzing the Charpy impact tests results and the hardness measurements, is suitable to estimate the austemper window starts between 30 and 60 minutes of austemper and ends between 90 and 120 minutes of austemper. As it is possible to observe in figure 3, at 60 and 90 minutes times the highest values of absorbed energy was measured.

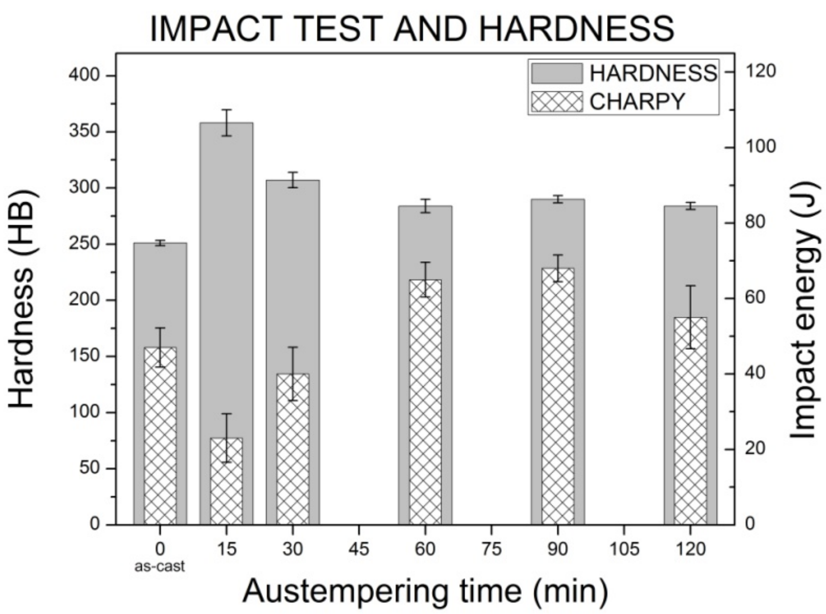

Figure 3. Toughness (ASTM E.23) and hardness.

On the simulations, the highest percentage of retained austenite is obtained at 35 and 40 minutes austemper times. All the results can be found in figure 4.

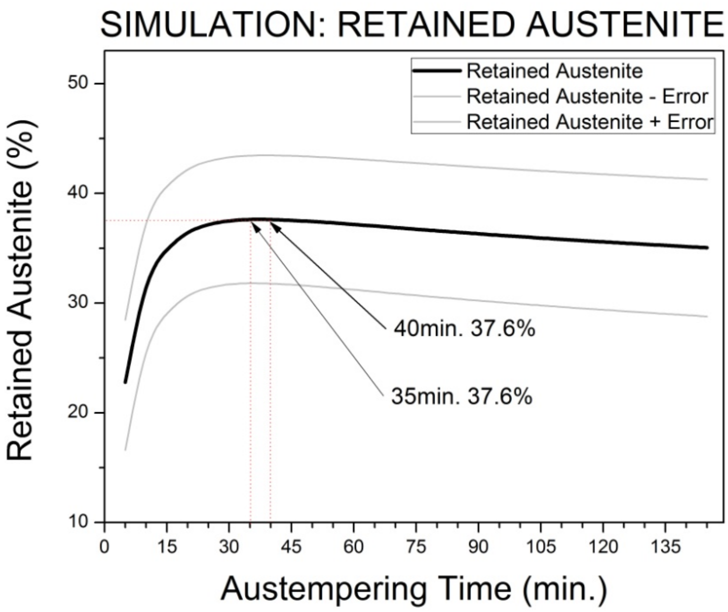

Figure 4. Simulation of retained austenite fraction as function of austemper time results.

The simulation results of retained austenite were partially coherent with the experimental results of Charpy impact tests, where the maximum percentage of retained austenite results in the highest toughness value. It is probable that the material used on the experimental tests presents alloy elements segregation, which explains the fact that the first stage of the austemper reaction was not completed yet, at 30 minutes of austemper.

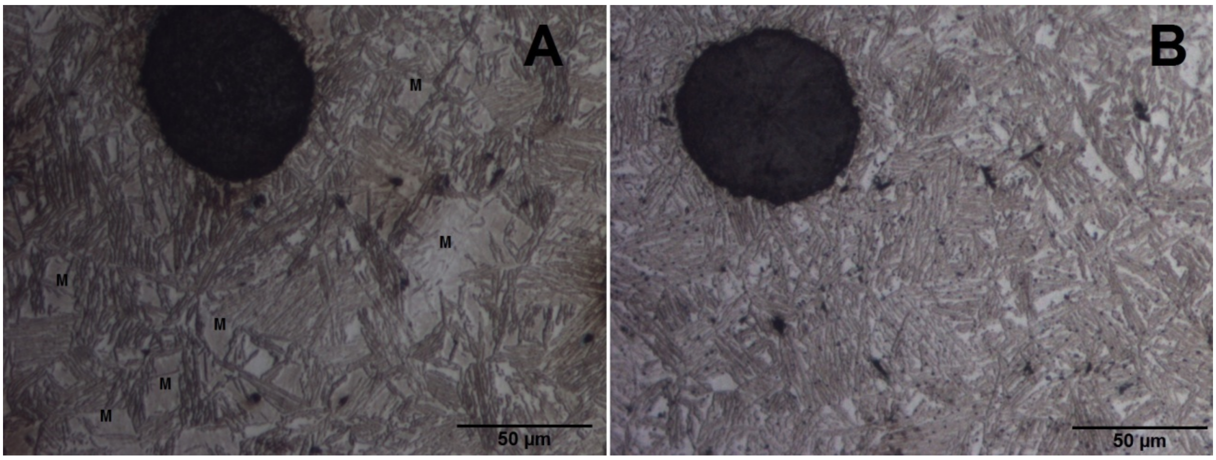

Figure 5. ADI microstructure of 30 minutes austemper cycle (A) and 60 minutes austemper cycle (B). Letter M indications on the micrographies indicate the regions where martensite formation occurred.

The segregation hypothesis as explanation of the delay to the first stage of austemper accomplishment is well evidenced with martensite formation in some regions, as can be observed in figure 5A.

3 CONCLUSION

In the development of a new ADI it must be considered the peculiarities involved in a treatment cycle of industrial scale, as well as the heterogeneity of the material in different sections of a component. However, the use of a simulation program to predict the process window, or ideal austemper time, demonstrated potential towards the reduction of experimental tests amount to process window determination.

Acknowledgments

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