

## Influence of Heat Treatment Processing Three Phase Region on the Microstructure and Hardness ADI Alloys

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### ABSTRACT

In this paper, the Austempering Ductile Iron (ADI) with Dual Matrix Structure is the alloy which has high strength and ductility, good wear resistance and machinability. Structural studies show that in ADI bridge cast iron there are proeutectic ferrite and ausferrite phases. The ausferrite phase is characterized by a phase that has ferrite and is rich in carbon in its structure. The heat treatment process of the research alloy is performed as follows: The alloy is heated to a completely austenite state in the temperature range from 870 to 930°C for a period of 90 to 120 minutes, then alloy It was incubated in a three-phase zone for 90 minutes and finally austempered at 360 °C for 120 minutes. This heat treatment creates an microstructure with a structure consisting of proeutectoid ferrite and ausferrite. The mechanical properties of the research alloy depend on the proportion of the ferrite phase that depends on the heat treatment process in the three-phase region.

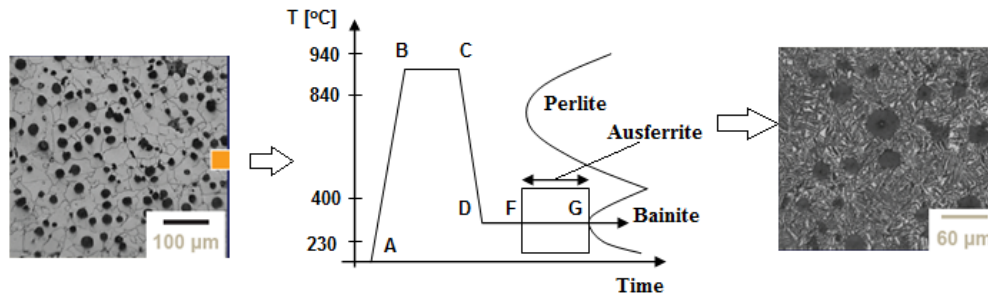
### KEYWORDS

Austempering Ductile Iron, mechanical properties, heat treatment, ferrite, ausferrite.

### INTRODUCTION

The technology of making austempering ductile iron (ADI) is an advanced achievement in cast iron technology. The traditional material for the making of ADI is nodular cast iron with high spheroidization. The structure of this alloys consists of the ferrite phase in the high carbon austenite which called ausferrite. This structure is formed by the isothermal heat treatment at temperature at which the carbon saturated austenite transforms to the acicular ferrite and high carbon austenite (Figure 1). There are some factors as the chemical composition, cooling rate, liquid treatment, as well as implemented heat treatments which effects the microstructure and mechanical properties of ADI. According to E. V. Pereloma and C. S. Anderson: “The process of heat treatment of ADI consists of austenitisation in the range of 870-930°C, where the as-cast matrix (pearlitic, ferritic) transforms into austenite and there is also an enrichment of austenite with carbon from the graphite nodules. Austenitization is followed by rapid cooling to the range of 250-450°C with isothermal holding for a time required for the transformation to take place. A two-stage phase transformation takes place in ADI” [1]. In the first stage, the metastable austenite ( $\gamma$ ) transforms to acicular ferrite (AF) and high carbon austenite ( $\gamma_{HC}$ ):

$$\gamma \rightarrow AF + \gamma_{HC}. \quad (1)$$



**Figure 1.** Illustration of making the austempering ductile iron (ADI)

Reaction (1) is caused by carbon secreted from the ferrite sheets to be converted into austenite [2]. In ADI cast iron, with the carbon content in austenite can reach 1.8-2.2wt.% Which has good general mechanical properties and heat resistance at high temperatures. Furthermore, this austenite phase does not turn into mactenxite. After heat treatment in the austenitic for a long time, the austenite phase with high carbon content ( $\gamma_{HC}$ ) can decompose into bainite (ferrite and iron carbides) which is formed in the second stage of alloy. In the alloys after treatment, martensites and carbides are undesirable phases for the mechanical properties of ADI. The final microscopic organization of ADI alloys are graphite spheres that form on the basis of plate ferrite and high carbon austenitic [3-7]. This structure of ADI exhibits a tensile strength 1100 MPa and a ductility about 5 %.

The effects of fusion element on the kinetics of ADI have been presented in a number of recent scientific works [7-10]. These studies have shown that in phase 1 of the reaction will be delayed if the ductile iron is alloyed with some alloying elements. In Cu, Ni, and Mo alloyed cast iron, the bainite transition is initiated with longer intervals. If the alloy is alloyed simultaneously, both Cu and Ni elements will significantly reduce the conversion rate of bainite. Furthermore, alloying with large amounts of Cu or the simultaneous addition of both the Cu and Ni elements changes the transformation rate values over time [7]. Perez and the authors believe that when the Si content decreases, the early reaction will begin. In the initial stage, more copper alloying and at the same time both the elements Cu and Ni with greater concentrations slow down and there is a large shift in reaction to the right [8]. The results of this study indicate that growth of ferrite sheets is due to the non-diffusion process [10]. When the alloy is alloyed at the same time both Cu and Ni, the reaction time will be the largest and the lowest rate of change in the first stage of the reaction.

In the practices, some suspension parts of automotive need a lower strength (about 600-700 MPa) and higher ductility (about 20-30%) than that of the conventionally heat treated ADI. The austempered ductile iron with dual matrix has been found to be satisfied these needs [3, 11-15]. The structure of this ADI with dual matrix consists of proeutectoid ferrite phase and ausferrite. This structure is obtained by fully austenitization, then holding at temperature at which both ferrite and austenite are present, rapidly enough austempering for almost all austenite to transform into ausferrite. The proeutectoid ferrite don't transform so, the final microstructure of dual matrix ADI contains proeutectoid ferrite and ausferrite. The volume fractions of ferrite proeutectoid and ausferrite can be controlled to determine ADI's strength and ductility with double matrix structure. New ferrite is a measurable parameter that can control and influence the tensile behavior of a non-alloy ductile iron. Plasticity increases with increasing the volume of new ferrite [11].

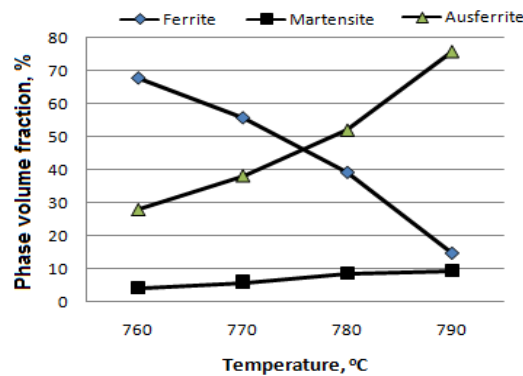
The total volume fraction of the transformed phases is virtually constant for all extreme times after the rapid conversion of samples from a particular critical temperature. The carbon content in austenitic has a great influence on the reduction of new ferrite growth rate [3, 11-15]. Temperature and time of this procedure have significal effects on the ferrite fraction of dual matrix ADI, in turn, significal effects on it's mechanical properties. It's possible to control the proeutectoid ferrite by controlling the temperature and time during austenitising in the three phase region, so that to control the mechanical properties of dual matrix ADI [14, 16, 17]. The purpose of the present study is to quantify effects of temperature in three phase region on the proeutectoid ferrite fration of austempering ductile iron with dual matrix.



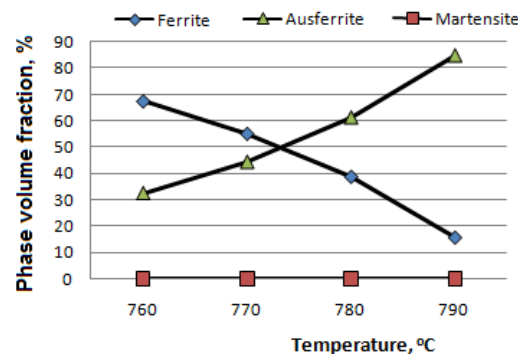
## Proeutectoid ferrite fraction at different temperature

The microstructure of samples shows that the shorter is austempering time, the higher the martensite fraction is. After austempering for a short time (5-30 min) a few acicular ferrite and high carbon austenite were formed at the boundary between ferrite and martensite. When the austempering time increases up to 60 and 90 min. almost martensite is displaced by acicular ferrite and high carbon austenite, the martensite fraction is very small. If austempering time is 120 min, there isn't any martensite, microstructure of sample is fully proeutectoid ferrite and ausferrite. If the austempering time is longer than 120 min. no reaction occurs and the microstructure is more stable and more uniform. Based on sample microstructure and by using the multiphase software the volum fractions of ferrite, martensite and ausferrite during austempering were determined. In this stage the excess carbon diffuses into austenite, which was enriched in carbon and becomes more stable ( $\gamma \rightarrow \alpha_b + \gamma_{HC}$ ).

The volum fractions of proeutectoid ferrite, martensite and ausferrite are illustrated in fig. 3 and 4. The heat treatment is followed: austenitisation at 900°C for 2 h; annealing in three phase region for 2 h; austempering at 360°C for 90 min (fig.3) and for 120 min (fig.4). Figures 3 and 4 show that proeutectoid ferrite fraction increases with decreasing temperature in three phase region. This can be explained by changing carbon content (tab.1). As temperature of three phase region increases, carbon content in austenite increases too. Austenite becomes more stable and more difficultly transforms into ferrite. As austenitising at 900 °C for 2h, annealing at high temperature 780°C and then austempering at 360°C for short time, proeutectoid ferrite fraction is low, about 15% and it's distribution is not uniform. As austempering time increases up to 120 min, microstructure of ADI consists of only proeutectoid ferrite and ausferrite.



**Figure 3.** Phase fraction and temperature in three phase region: austenitization 900°C for 2h; holding at three phase region for 2h; austempering at 360°C for 90 min.



**Figure 4.** Phase fraction and temperature in three phase region: austenitization 900°C for 2h; holding at three phase region for 2h; austempering at 360°C for 120 min.

When cooling to room temperature, the low carbon austenite will transform into martensite, increasing hardness, wear resistance and decreasing ductile property of ADI. In the other hand, because the special volum of acicular ferrite is greater than that of austenite, the growth of austenite is suppressed. If the holding time is too long,

austenite becomes more enriched in carbon, more stable and difficultly transforms to ausferrite. The holding austempering time is shorter than 90 min. austenite has low stability and a part of them will easily transforms into martensite. Increasing the austempering time the volum fraction of martensite decreases, the volum fraction of ausferrite increases, the fraction of proeutectoid ferrite don't change (fig.5).

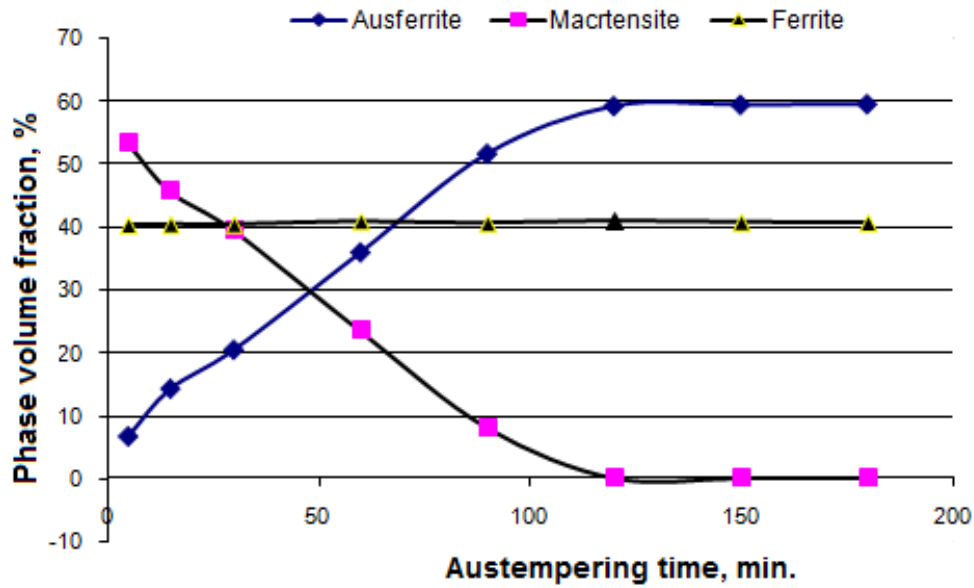
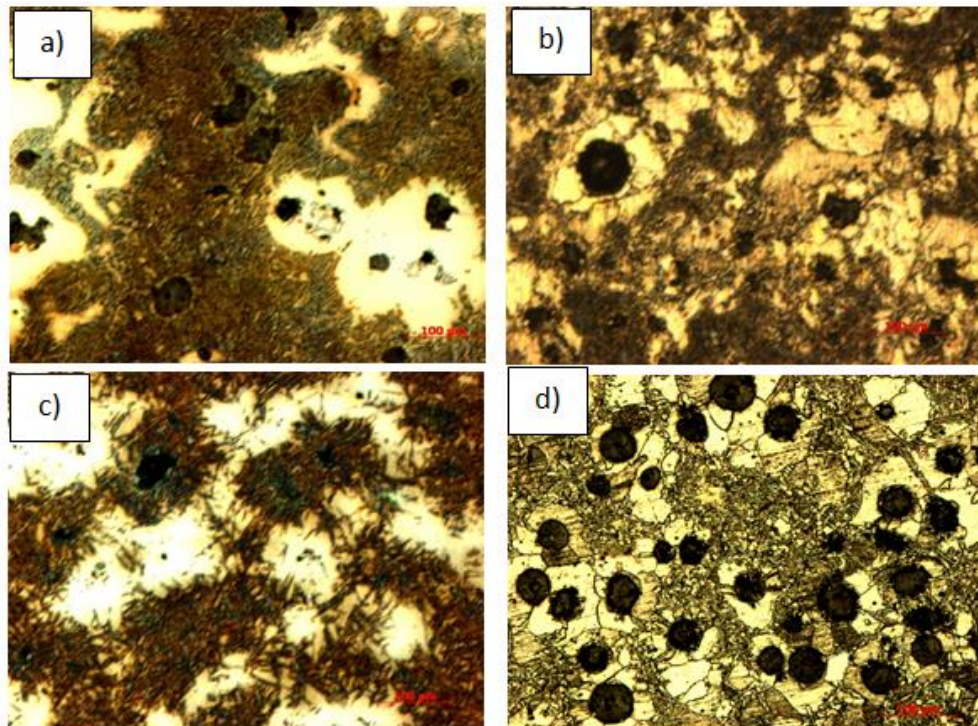


Figure 5. Phase fraction and austempering time. Austenitization 900°C for 2h; holding at 780°C for 2h; austempering at 360°C.

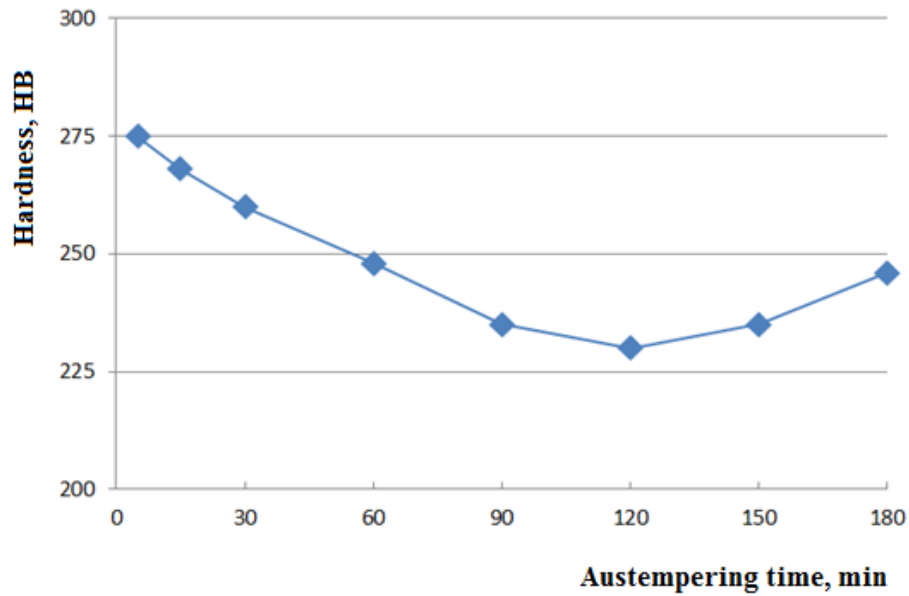


**Figure 6.** Microstructure of ADI with dual matrix. Austenitization at 900°C for 2h; aging at 780°C for 2h; Austempering at 360°C: a) 30 min., b) 60 min, c) 90 min., d) 120 min.

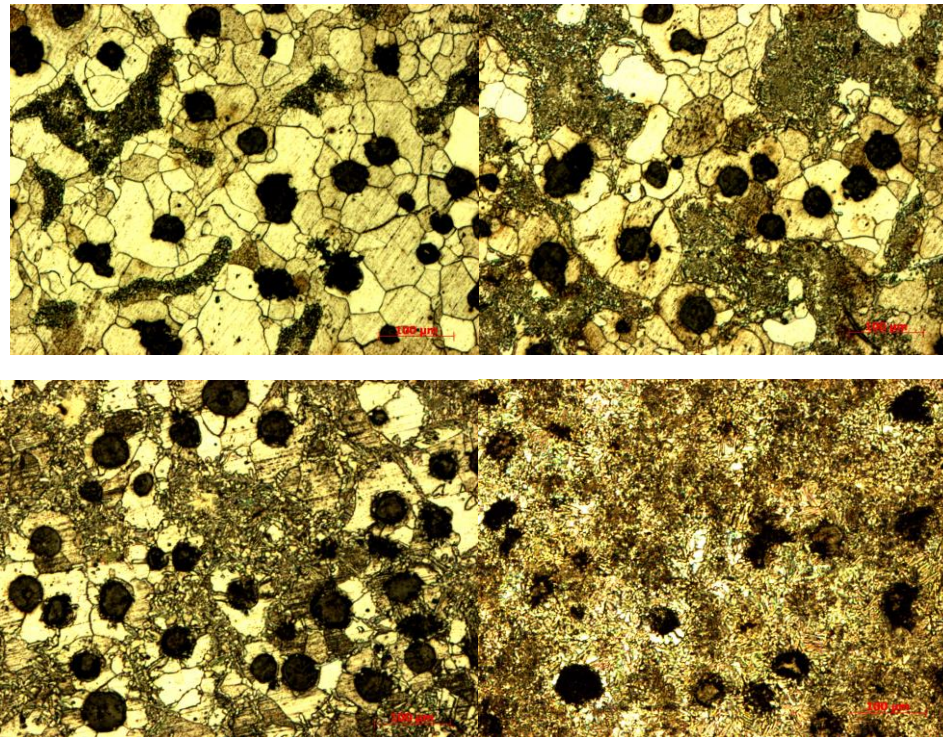
When the austempering time is longer than 100 min. the martensite fraction is very small, about 5% and remains 0% after holding time of 120 min. (fig.5). At that time, austenite becomes more enriched in carbon and doesn't transform to martensite when it is cooled in the room temperature. With further increasing austempering time



and stage I reaction approaches completion, system comes into “processing window”. The starting time of processing window is determined by the time at which there is less than 5wt.% martensite in the microstructure of ADI. In this study this time is shown to be 110 min.



**Figure 7.** Hardness and austempering time. Austenitization 900 oC for 2h, annealing at 770oC for 2 h ; austempering at 360oC.



**Figure 8.** Microstructure of ADI with dual matrix. Austenitization at 900oC for 2h; annealing in tree phase reange for 2h; Austempering at 360oC for 120 min.

Figure 7 showed that, ADI hardness decreased when heat treatment austempering time is increased to 120 min. at which the last austenite stabilised enough and don't to transform to ausferrite. In the range of the austempering time between 120 to 180 min, no raeaction occurs and microstructure of ADI is rearranged and becomes more stable and uniform. Consequently, hardness increase. System aproachs processing window. Fig.8

showed the effect of three phase range temperature on the proeutectoid ferrite fraction. It's clear that the higher temperature in three phase region is, the lower is the ferrite fraction. This can be explained that at low temperature the carbon content in parent austenite decreases with decreasing the intercritical austenitisation temperature and austenite easily transforms into proeutectoid ferrite. The transformation of ductile iron is an important feature that is highly dependent on the ferrite proeutectoid ratio, which is influenced by the austempering time and temperature of three phase region. Due to the formation process proeutectoid ferrite which contains less impurities than cast ferrite and has a more stable structure than this phase. So, proeutectoid ferrite is expected to have higher ductility than as-cast ferrite.

**Table 1.** Effects of austenitization temperature on %C of austenite

Austenitization temperature, °C	Carbon content at austempering time, % (by weight)			
	Austempering time, min.			
	0'	30'	45'	90'
870	0,630	0,678	0,850	0,90
900	0,639	0,750	0,924	1,11
930	0,642	1,140	1,180	1,18

Table 1 and matrix structure on fig.8 show that the carbon content in austenite increases with increasing austenitization temperature and the ausferrite fraction increases too. This can be explained by diffusion process of carbon in the matrix. Increasing temperature increases the diffusivity of carbon. Carbon atoms easily diffuse from perlite into austenite, increasing the carbon content in austenite. High carbon content makes austenite less stable and the austenite easily transforms to ausferrite. Consequently, ausferrite fraction increases. Increasing the full austenitising temperature causes the increase in the carbon content of austenite. It means that the driving force of transformation  $\gamma \rightarrow \alpha$  in three phase region and the driving force of the quenching stage reaction decrease. Thus the amount of proeutectoid ferrite decreases. Consequently, the formation of ausferrite is delayed and the processing window is shifted to longer austempering times.

## CONCLUSIONS

For the studying ductile iron there is a three-phase region on its phase diagram. The three-phase temperature range of this iron is 750-800°C. For the ADI with dual matrix the proeutectoid ferrite fraction decreases with increasing the three-phase temperature. The proeutectoid ferrite fraction can be controlled by controlling the three-phase temperature and by full austenitisation temperature. It is possible to control the microstructure and mechanical properties of ADI with dual matrix by controlling the heat treatment conditions: austenitizing temperature and time; temperature and holding time in three phase regions; austempering temperature and time.

## ACKNOWLEDGMENTS

Thanks to the supports from Faculty of basic science - VMU, School of Materials Science And Engineering – HUST. This is appreciated acknowledgment for me to complete this study.

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