ARCHIVES
of
FOUNDRY ENGINEERING
Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

ISSN (1897-3310)
Volume 13
Special Issue
1/2013
91–96

17/1

Searching for Better Properties of ADI

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Abstract

The results of study of austempered ductile iron using different methods of austempering are presented. Except changing time, temperature of austenitizing and isothermal quenching, direct quenching, two-step quenching followed solution heat treatment (austenitizing) was proposed. The goal of this paper is to discuss the results obtained for ductile cast iron subjected two step austempering. Ultimate tensile strength, elongation, hardness, and fracture toughness, thermal stability were compared. Two-step quenching method of hardening seems to be promising.

Key words: ADI; Structure; Properties.

1. Introduction

Recently austemperd ductile iron - ADI [1] still looks to be probably the most interesting achievement in the metallurgy of cast iron. ADI has many desirable mechanical properties, such as high strength (ranges from 800 up to 1600MPa and even more) [2] good ductility [3-5], good fatigue strength [6–9], the tensile strength fracture toughness [10-14] and wear resistance [15]. These properties have made ADI an attractive engineering material in structural applications in car-industry (gears, crankshafts, support wheels etc.) for instance [1, 16]. Another advantage of ADI is relative simple and cheap technology involving solution heat treatment at the temperature 850–950 ^{o}C which is followed by isothermal quenching at the temperature range of 250–400 ^{o}C. Use of ADI is systematically growing as a "discovery" of mechanical properties, economical and low technological requirements. Figure 1 shows the application of ADI in various branches of industry, followed by examples of specific applications. The properties of ADI depend on structure of metal matrix formed during isothermal quenching.

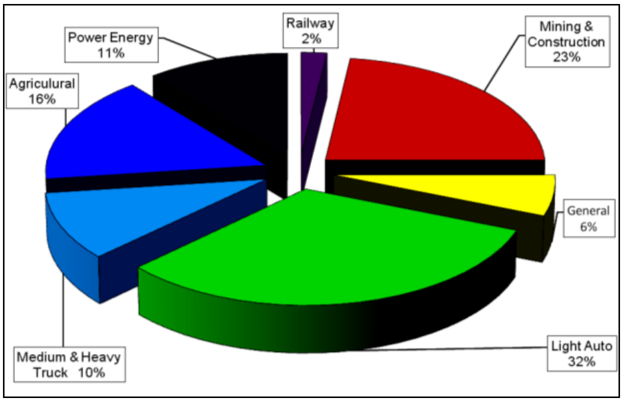


Fig.1. The application of ADI in various industries

The typical microstructure consists of ferrite and high carbon austenite. Impressive mechanical properties of ADI led to take in many scientific centers around the world of intense research aimed in finding the relation between the parameters of heat treatment, microstructure and mechanical properties of ductile cast iron. Such studies has been also started relatively early also in Poland [17–21].

Despite very good mechanical properties of ADI the engineers are still looking for better combination of strength, ductility and fracture toughness. Except changing time and temperature of austenitizing and isothermal quenching, two-step quenching followed solution heat treatment (austenitizing) was proposed by Yang and Putapunda [22] and Putapunda [23]. Such a study was carried also by Kaczorowski and Krzyńska [24, 25]. The goal of this paper is to discuss the results obtained for ductile cast iron subjected two step austempering.

2. Structure

The microstructure of ADI matrix - the share of each component depends mainly on the temperature and time of isothermal quenching. Thus, low temperature isothermal quenching (260 - 290°C), promotes the formation of a mixture of acicular ferrite (Fig.1a) and austenite, where the amount of the last component is relatively small. On the other hand, during high temperature (350-400°C) isothermal quenching mixture of rather feather-like ferrite (fig.1b) and carbon supersaturated austenite is formed. In this case the, depends on time of quenching, the relative amount of carbon stabilized austenite can reach even 40%.

Share of retained austenite has a decisive influence on the behavior of ADI under load. As you might guess, the larger amount of FCC austenite to greater ductility of ADI which is manifested in the form of characteristic morphology of fracture surface (Fig.2b). In case of low-temperature and short-time isothermal quenching small amount of martensite may be discovered in ADI matrix.

The appearance of hard and brittle martensite adversely affects the plastic properties of ADI.

Although conventional metallography is very useful and convenient method for microstructure investigations it is limited by small resolution which make impossible to discover details of structure. These details can be much better illustrated using thin foils observed in transmission electron microscopy (TEM). These observations allowed seeing not only the morphology of the phases but also delivering some additional information on defects introduced during heat treatment or behavior during mechanical loading. The only limitation of TEM technique is very difficult thin foils preparation, especially two- or multiphase materials. Such difficulties are meeting in case of cast iron consisting of metal matrix and graphite nodules, which behavior during thinning is very different. These difficulties can be overcome by complicated thinning involving dimpling and then ion-milling. Some results of TEM investigations are given in fig.3.). The first micrograph (fig.3a) shows mainly ferrite grains with many dislocations inside it, while in the second (fig.3b) austenite with many stacking faults are visible. In third electron micrograph (fig.3c) example of martensite was depicted.

a.

b.

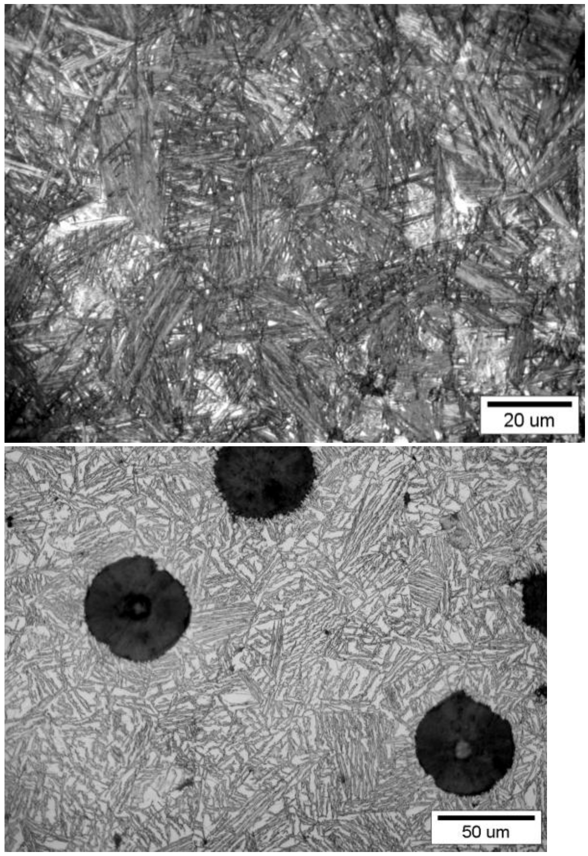


Fig. 1. The microstructure of ADI as function of 90 min. austempering at: a – 275°C and b – 360°C

3. Results and discussion

As was said earlier, looking for better combination of strength and ductility of ADI led to the search for other methods of isothermal quenching. One of these possibilities is a two-stage hardening, carried out in several versions. One of them is the short time quenching at relative high temperature (e.g. 350-350°C), followed by quenching at lower temperature [24, 25]. The aim of first-stage quenching is stabilizing of austenite caused by its carbon supersaturation, thereby preserving high proportion of austenite in ADI matrix. As was said before, the higher austenite content, the higher ductility of ADI. The second-stage of quenching which is carried out at lower temperature, should cause the transformation of austenite into ferrite, but because of stabilization of austenite with carbon only part of it will transforms into ferrite.

a.

b.

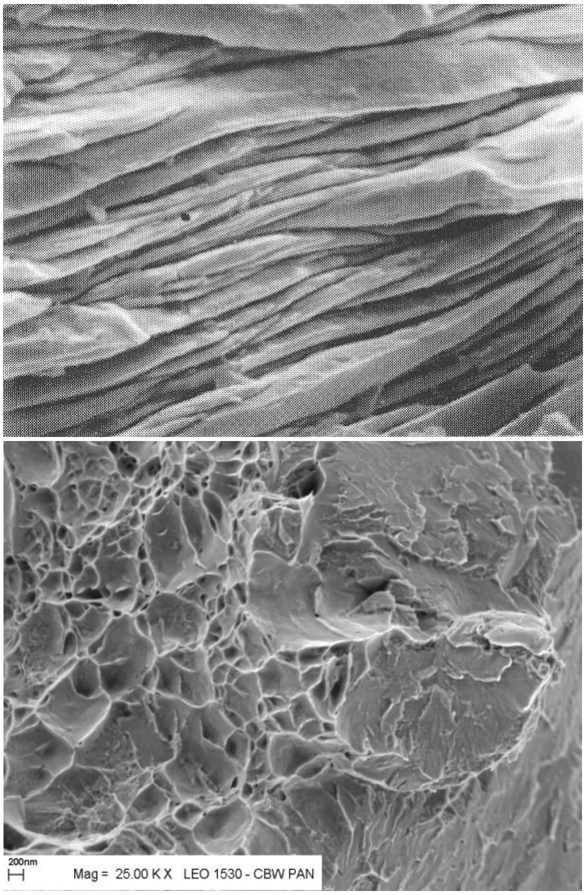


Fig. 2. The morphology of fracture surface of ADI austempered at: a – 275°C and b – 360°C

The characteristic features of martensite grain visible in fig.3c are very thin microtwins which can be easy identified at higher magnification. It can be discovered that the microtwins in the grain showed above (fig.3c) are almost parallel to the martensite boundary.

The second option proposed by Putatunda [22] aimed to ensure the high dispersion of structural components, especially ferrite. It consists in a rapid cooling to a low temperature range between 260-375°C at which the castings were kept 5 minutes, and then held to the time of 2 hours in a temperature rising rate of 14°C/h. The second variant proposed by Yang and Putapunda [23] consisted in 5min. quenching at low temperature in range 260-375°C and then 2 hours austempering at a temperature of about 30° C higher than the temperature of the first stage of austempering. As a result of these studies the authors found a significant effect of a two-stage austempering on the microstructure ADI. First of all they reported that during the hardening process at the same temperature, the share of austenite in ADI increases, compared to a single-stage hardening. Secondly they noted that the two-stage quenching leads to a higher austenite supersaturated with carbon. The result is that the total content of carbon in austenite is also growing. Another result of these researches on two-stage austempering was that the two-stage quenching led to fragmentation of the ferrite grains. It is understood that the fragmentation of ferrite favorably affects the properties of the ADI which is understandable if Hall-Petch relationship will be taken into account.

a.

b.

c.

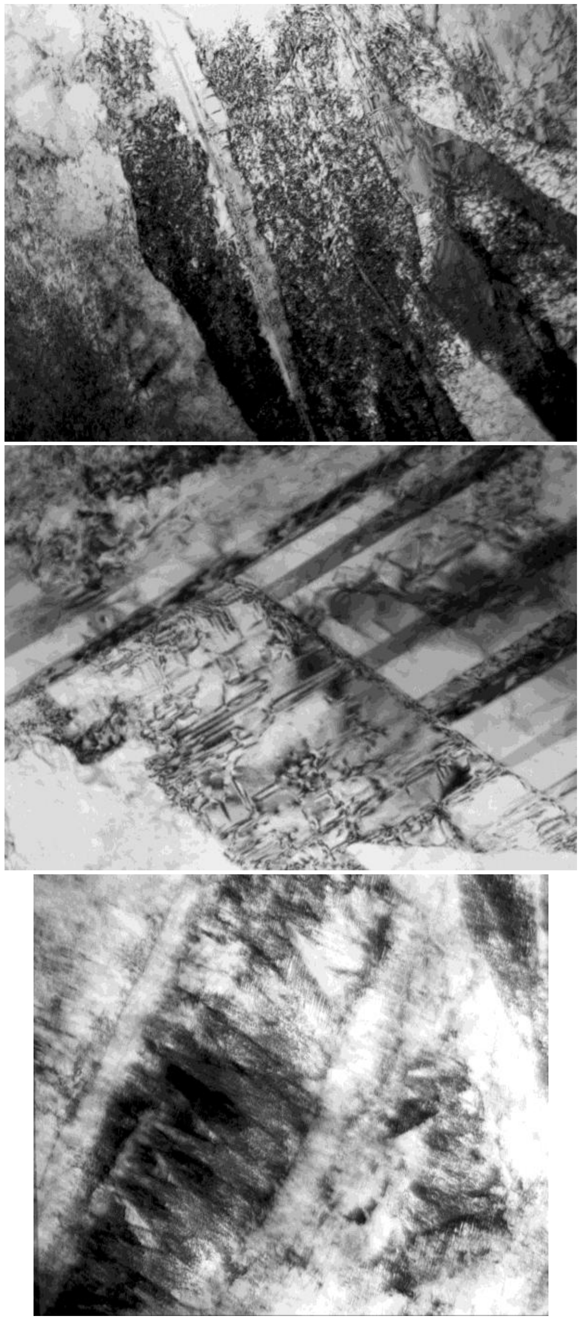
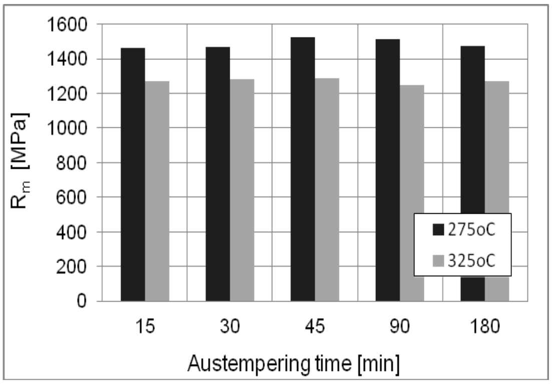


Fig. 3. TEM micrograph of ADI constituents: a – ferrite needle (x22.000), b – austenite (x35.000), c – martensite (x60.000) [20]

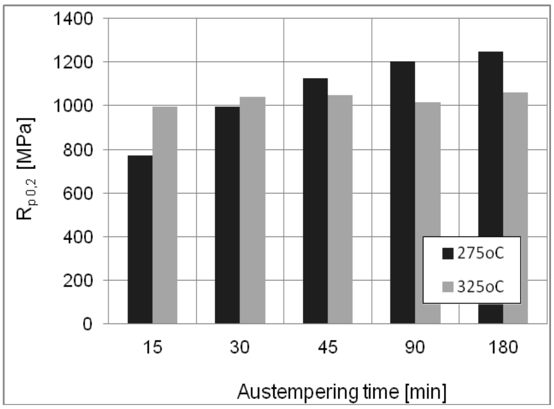
It is worth to mention one more method of isothermal austempering of spheroidal graphite cast iron, which primarily motivated by cost reduction heat treatment. The starting point was to note that during the casting cooling, when it is removed from the mold, the temperature decreases gradually and over a period of time it is in the range to the austenitizing temperature. Thus, the casting at temperature at which the solubility of carbon in austenite is the maximum could be put into the medium with a temperature in the range of the isothermal annealing, i.e. 260-400^{o}C, depending on the desired structure of the ADI [26, 27]. A shortcoming of this simplified method is the heterogeneity of quenching temperature on the cross-section of the casting, which may result in non-uniformity of the chemical composition. Such a direct method used in the isothermal austempering Foundry Institute of Technology Department of Materials.

It is obvious that the parameters of the isothermal tempering, particularly temperature and time affects the structure and then the mechanical properties of ADI. Fig. 4 presents the results of our research concerning 500-7 iron grade ductile iron, austenitized 60 minutes at 900°C, and then isothermally quenched at the temperature 275 and 325^{o}C for time t = 15, 30, 45, 90 and 180 minutes. As can be seen from the graphs (fig. 4a, b) isothermal quenching at lower temperature (275 ^{o}C) provides higher strength properties than austempering at higher temperature (325^{o}C).

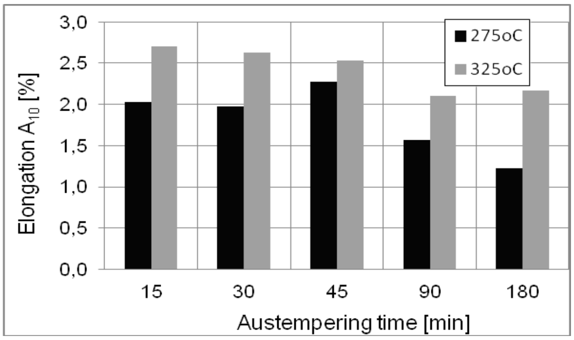
a.



b.



c.



d.

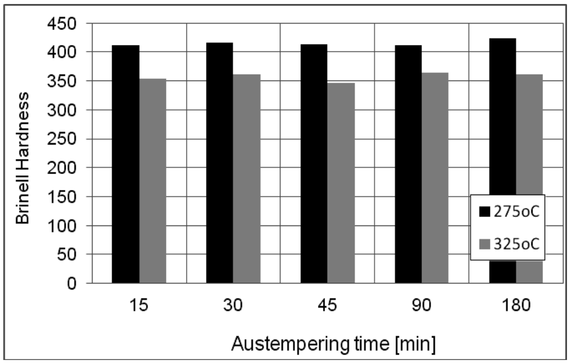


Fig. 4. The mechanical properties of ADI in function of time and temperature: a - R_m, b - $R_{p\,0,2}$, c - A_{10} and d – HB

The same can be observed for hardness measurement (fig.4d). On the other hand, elongation A_{10} is higher in case of austempering at 325^{o}C compare to austempering at 275^{o}C. Similar results were obtained by Yang and Putatunda [23] who concluded that an increase in tempering temperature increases the tensile strength (Fig.5a), which takes place at the cost of elongation (fig.5b) for both: one- and two-step austempering.

The tensile strength is of course only one of the mechanical properties of engineering materials. When consider that the most significant feature of the ADI is its high hardness and wear resistance, there is no doubt that it would be very good to ADI simultaneously characterized by high resistance to brittle fracture. This feature material depends on two contradictory material properties such as strength and ductility. Therefore, they are very interesting results Putapunda, who concluded that the two-step quenching increases resistance to fracture as shown in Figure 6.

It is interesting to note that fracture toughness depends on the proportion of austenite which is responsible for ADI ductility. It should be also taken into account that the increase of carbon in austenite causes decrease of free carbon in the form of separate spheres. This in turn leads to an increase in cross-sectional area of the sample.

a.

b.

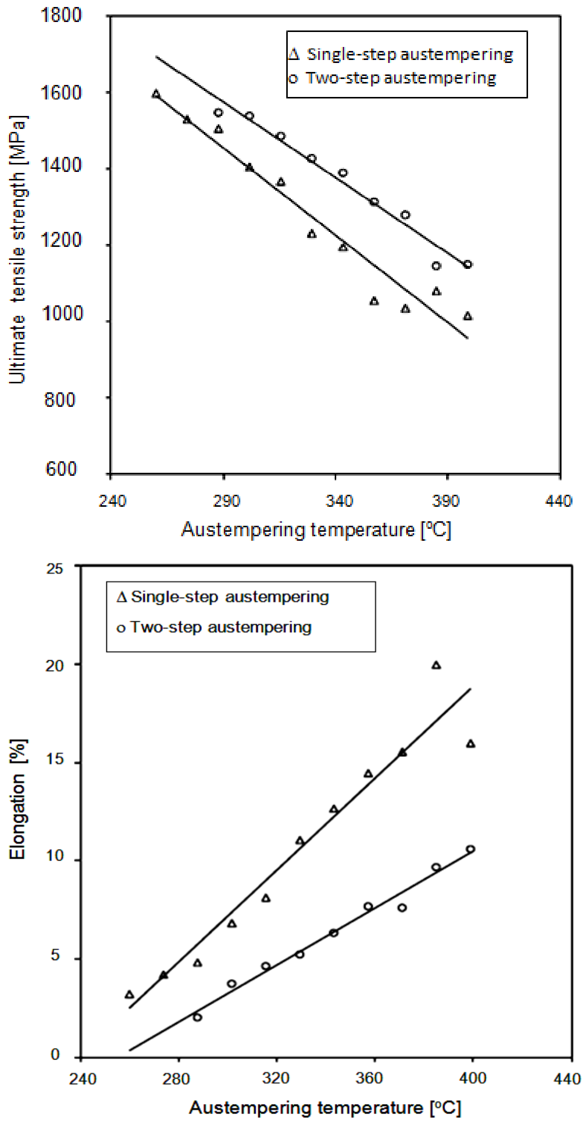


Fig. 5. Influence of temperature in case of one- and two-step austempering on: a - ultimate tensile strength, b - elongation

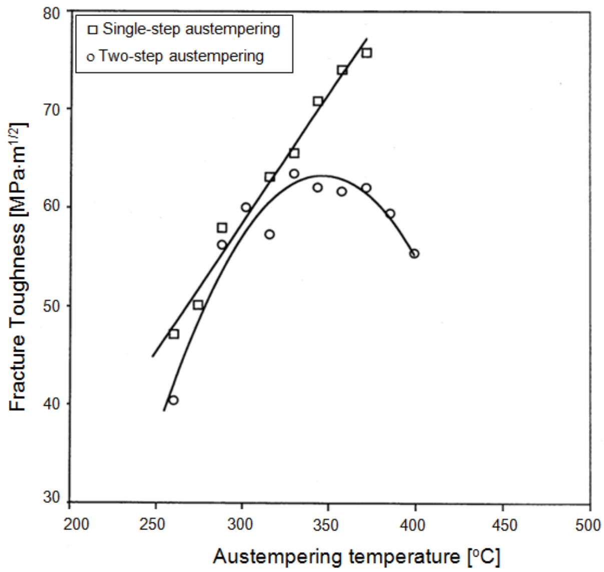


Fig. 6.The dependence of fracture toughness on the austempering temperature for one-step and two-step austempering

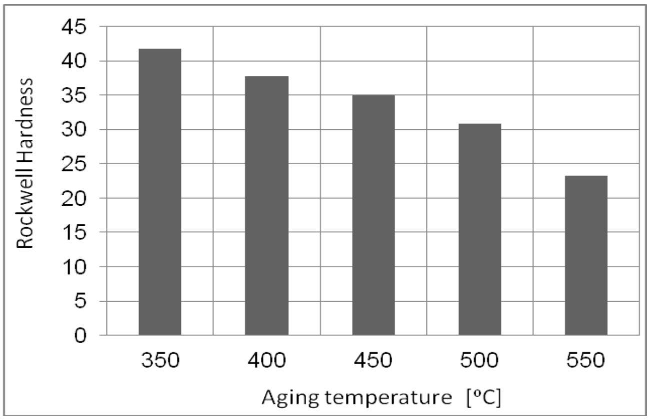


Fig.7. Rockwell hardness as a function of annealing temperature

In addition to the mechanical properties of an important parameter in the selection of the material is its thermal stability. The results of structure investigations of ADI during 360 min. annealing at temperature 400, 450, 500 and 550°C were presented in [26]. The structure investigations showed that annealing at these temperatures caused substantial structure changes and thus essential hardness decrease. The figure 7 shows the change in hardness with increasing annealing temperature.

Degradation advance of the ADI structure depends mainly on annealing temperature, less on the time of the heat treatment. It was concluded that high temperature annealing caused precipitation of Fe_3C type carbides, which morphology and distribution depend on temperature. Ausferrite decomposition cases substantial ADI hardness decrease which value depends on annealing temperature and change from 10 to 25% of starting value for 400 and 550°C respectively.

Researches on improving the properties of ADI are still conducted. Currently, at the Division of Metal Forming and Casting of Warsaw University of Technology there are carried out the research concerning the role of chemical composition, particularly silicon content, on the microstructure and mechanical properties of ADI.

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