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Influence of Pre-heat Treatment on Mechanical Properties of Austempered Ductile Cast Iron

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Abstract

The paper presents the effect of pre-heat treatment on the mechanical properties of ductile cast iron with elevated content of Cu and Mo elements. Austempered Ductile Iron is a material with non-standard properties, combining high tensile strength and abrasion resistance with very good plasticity. In addition, it is prone to strain hardening and have good machining abilities. The study was conducted for five designed heat treatment cycles. The variables were the time and temperature of the pre-heat treatment, followed by one of two standard heat treatments for ADI cast iron. The aim of the authors was fragmentation of the grains of perlite during the initial heat treatment. It is presumed, that subsequent heat treatment will cause further refinement of the microstructure than would be the case without initial heat treatment. Diffusion is much faster than in case of ferritic matrix of cast iron.
The results will be used to evaluate material for the production of parts of equipment that must operate under extreme load conditions.

Keywords: Ausferritic ductile iron, Heat treatment, JMatPro, CCT and TTT diagrams, SEM

1. Introduction

Austempered Ductile Iron (ADI) becomes a popular replacement for cast steel and welded construction, because of its high strength, abrasion resistance and impact strength. The excellent mechanical properties of cast iron are attributed to the unique microstructure with its high carbon austenite (γ_{HC}) and ferrite (α) content. [1-2]

The production cycle of the ausferrite matrix in cast iron consists of soaking the material above the critical temperature Ac1 (austenitization) and quenching, during which the critical cooling speed must be fast enough to prevent the conversion of austenite into perlite followed by an isothermal hold in the bainitic temperature range to convert austenite into ferrite and stabilize residual austenite. However, unstable retained austenite remains around the boundaries of eutectic cells. The unstable austenite reduces impact strength and machinability od ADI. [1-2]

The morphology of austempered ductile iron matrix microstructure largely depends on the duration of the isothermal transformations. If the transformation will last for a very short time, the cast iron matrix will be almost entirely martensitic, with a small amount of ferrite fraction. The longer the transition time is, the ferrite content in the matrix increases in the form of austenite-separated plates. Austenite stabilizes with increasing time. This results in the formation of a full ausferrtic matrix in cast iron. Bainitic microstructure is obtained after long periods of isothermal hold [3].

The matrix of ADI has several distinctive features, depending on the duration of the isothermal transformation. For short time of transformation, the iron matrix is almost completely martensitic, with a small amount of ferrite in the form of plates. With longer holding times, the amount of ferrite in the form of austenite-separated plates increases. Stabilization of austenite begins with even longer periods of isothermal transformation. In that case, the matrix will be fully ausferritic, with austenite in two forms: austenite-separated plates of ferrite, and block austenite between ferritic-austenitic packages [3].

Literature shows that the use of two-stage heat treatment in the manufacture of ADI is becoming increasingly attractive, mainly due to the significant improvement of the mechanical properties [4-6]. This treatment is called pre-heat (initial) treatment. By refining the perlite grains during the initial heat treatment, it is suspected that further heat treatment processes will result in even greater refinement of the microstructure, and consequently, the improvement of mechanical properties of cast iron.

2. Experimental procedure

Ductile iron with full perlitic matrix was used in this study. Table 1 shows the chemical composition of the material. Precision castings were melted at the Foundry Institute in Cracow. Metal was melted an induction furnace with capacity of 500kg. After that, spheroidization process was performed with NiCuMg17, using the Sandwich method. The stairs shape and venes castings to the shot blast machine were obtained. They were cast in ceramic molds and air cooled after pouring. The casts were cleaned by sandblasting.

Five sets of samples were made. A set was subjected to one of 5 different heat processes according to the schemes, shown in Fig. 1. The variables T and t of thermal processes were selected to allow to compares on of conventional heat treatments of cast iron (processes A,B from Fig. 4) and the effect of pre-heat (processes C-E from Fig.4). The temperatures and the holding times of conducted heat treatments were selected on the basis of analysis results by JMatPro program, This is simulation software that computes a wide range of material properties for alloys, especially multi-component alloys. JMatPro allows thermodynamic calculations, calculations of material constants as a function of temperature and chemical composition, and calculations of phase transitions and heat treatment.

For the heat treated samples, the following tests were conducted: metallography (electron scanning), hardness, tensile strength, impact test and dilatometric charts. In the case of tensile and impact strength tests, 3 samples were made for each of the heat treatment variants. The isothermal process was carried out in a fluidized bed.

3. Experimental results

3.1. Dilatometric studies and CCT and TTT diagrams from JMatPro program

Fig. 1 is a dilatometer diagram which shows characteristic temperatures – Ac1 equal to 780,5°C, Ac3 equal to 883,2°C.

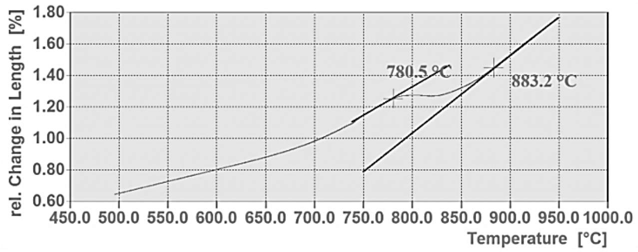

Fig. 1. Dilatometric diagram for the tested CuMo cast iron

With the JMatPro program, TTT and CCT charts were obtained by introducing a given CuMo cast iron composition into the program. Obtained charts are shown in Fig. 2 and Fig. 3.

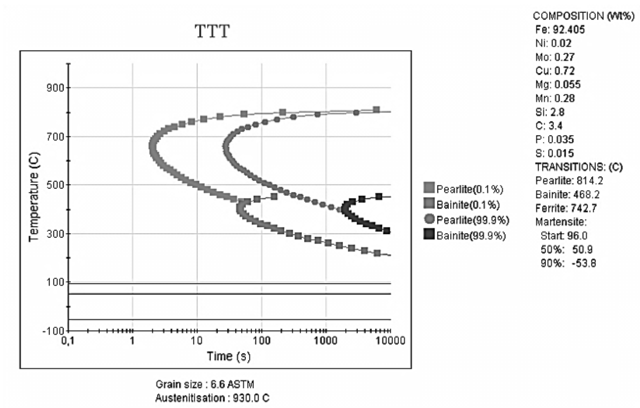

Fig. 2. TTT diagram of tested CuMo cast iron

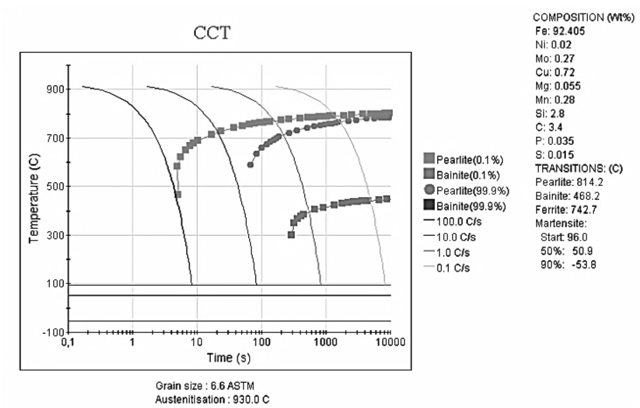

Fig. 3. CCT diagram of tested CuMo cast iron

Table 1.
Chemical composition of test material [mass pct]

C	Si	Mn	P	S	Ni	Mg	Cu	Mo
3,4	2,8	0,28	0,035	0,015	0,02	0,055	0,72	0,27

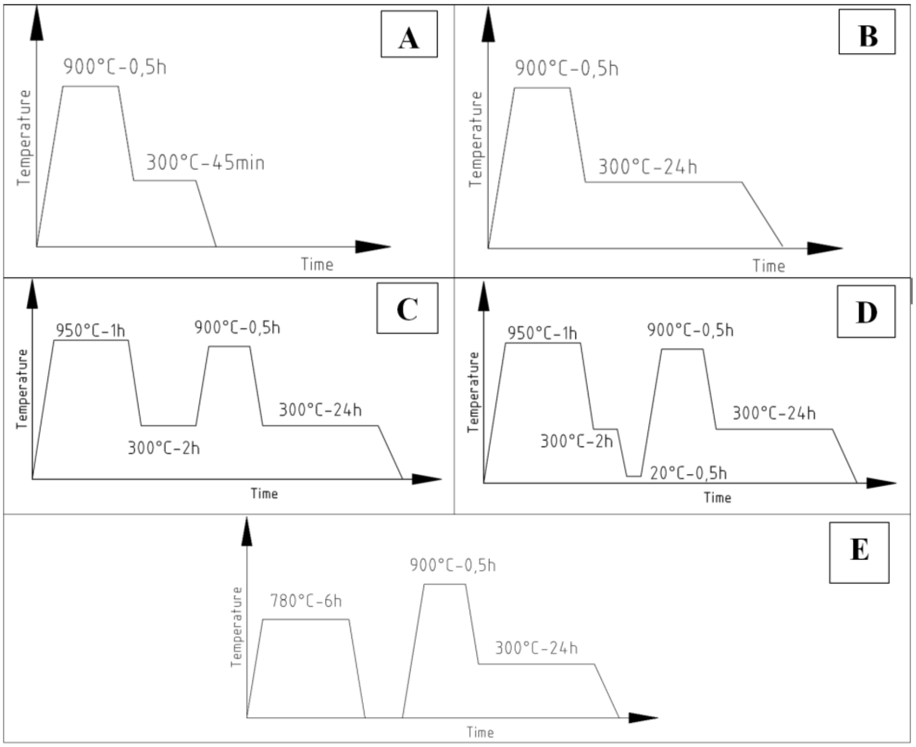

Fig. 4. Schemes of conducted heat treatment processes of CuMo ductile iron

3.2. Study of mechanical properties

The following graphs summarize mechanical properties of CuMo cast iron samples after heat treatment in particular: hardness comparison (Fig.5), impact strength (Fig.6), tensile strength along with deformation (Fig.7). The values shown for each parameter represent the arithmetic mean from all tested samples. Results include error bars.

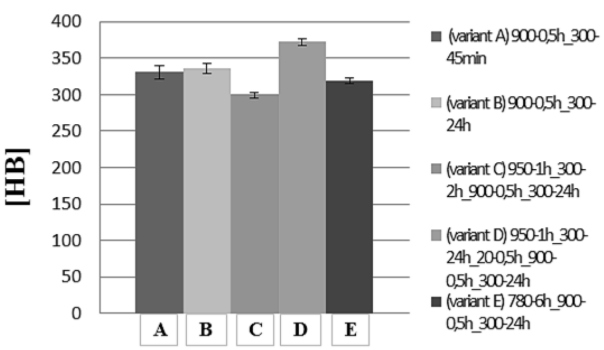

Fig. 5. Comparison of average hardness values for different variants of heat treatment of CuMo cast iron

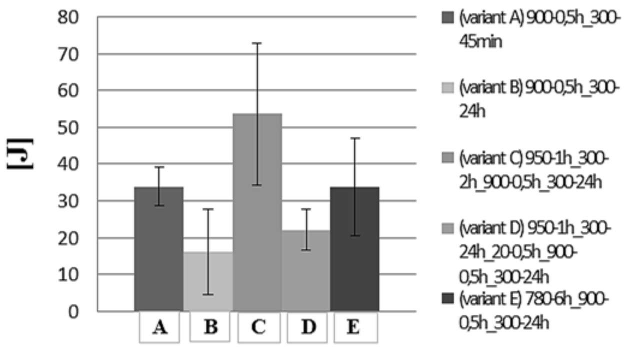

Fig. 6. Comparison of average impact strength after each of five different variants of heat treatment of CuMo cast iron

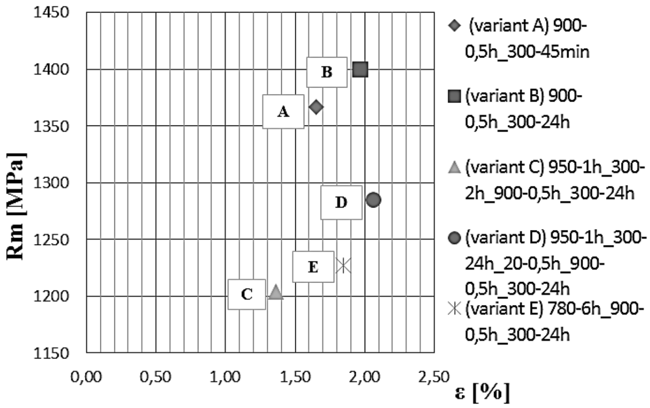

Fig. 7. Summary of average value of Rm and ε for different variants of heat treatment of CuMo cast iron

3.3. Study of microstructure

Figure 8 shows the SEM images of microstructures received after heat treatment processes. Average values of the tested mechanical parameters were added to the images. Noticeable is the fragmentation of the ferrite plates in the case of treatments with a descent to room temperature (D-E). Microstructures after other processes (A-C) are characterized by similar morphology

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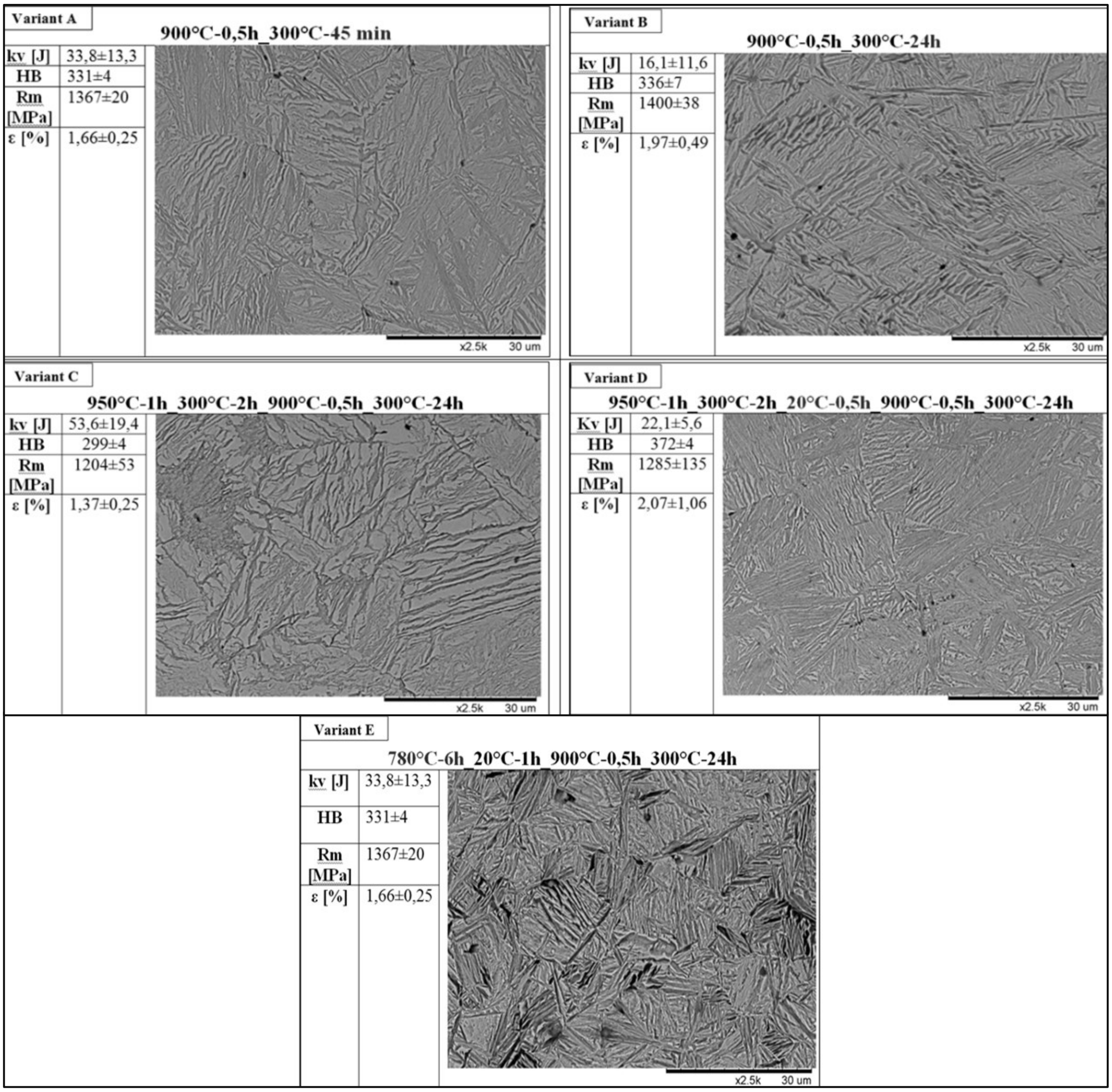

Fig. 8. Microstructure obtained from the SEM microscope of ADI for the applied heat treatment variants (etched by nital)

4. Discussion of research results

As a result of the conducted heat treatment, an ausferritic microstructure was obtained. Significant grain growth is noticeable in the case of double austenitization, which results in lower tensile strength and elongation – the sample is characterized by the lowest values of these two parameters. Also the impact value is one of the lowest for this heat treatment variant with double austenitization. Conducting the thermal process with descent to room temperature, after the first isothermal hold, processed resulted in the fragmentation of the bainitic ferrite plates. The sample had the highest values of hardness, tensile strength and elongation.

The morphology of the structure obtained after the short and the long conventional heat treatment process is similar for ductile iron of isothermal hold. Moreover, these samples achieved the best tensile and elongation values.

Because of a relatively large spread of the values of mechanical parameters, especially in case of impact test, we suggest to test more specimens.

5. Conclusion

Initial heat treatment of ductile cast iron with increased content of Cu and Mo elements seems to improve some mechanical properties. In the next phase we plan to repeat the test for ductile iron with a different chemical composition.

A careful study of the impact of individual elements on the microstructure and the mechanical properties of the cast iron should be made. The paper [7] describes the statistical analysis of the influence of Cu and Ni on the mechanical properties of spheroidal cast iron.

The description in the Introduction of the transformations of microstructure of ausferritic ductile iron matrix is not exactly characterized by the austenite phase. It is therefore justified to investigate austenite in the microscale, which was formed after isothermal quenching, because then the ausferrite, which is decisive for mechanical properties, is finally formed.

For this type of research, it is very difficult to find a single parameter that decides whether to accept or exclude a sample processed according to an established pattern

JMatPro software is a useful tool to support the design of heat treatment processes but as results should be carefully verified by testing samples. Therefore, dilatometric studies are indispensable for design of heat treatment processes.

Acknowledgements

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