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INFLUECE OF THE AUSTEMPERING TEMPERATURE ON THE TENSILE STRENGTH OF THE AUSTEMPERED DUCTILE IRON (ADI) SAMPLES

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Preliminary Note – Prethodno priopćenje

Austempered Ductile Iron (ADI) is a class of ductile iron subjected to a two-step heat treatment process – austenitization and austempering. The heat treatment gives to ADI a high value of tensile strength and an especially good strength-to-weight ratio. However, designers in most cases are unfamiliar with this material that can compete favorably with steel and aluminum castings, weldments and forgings. The high tensile strength of ADI is the result of its unique ausferrite microstructure. In this paper, an investigation of the influence of the austempering temperature on the tensile strength of the ADI samples is presented.

Key words: ADI, austempering, temperature, tensile strength, microstructure

INTRODUCTION

Austempering is a heat treatment process that is applied to ferrous metals, most notably for steel and ductile iron. In steel it produces a bainite microstructure whereas in cast iron it produces a structure of acicular ferrite and high carbon, a stabilized austenite known as ausferrite. It is primarily used to improve mechanical properties or reduce/eliminate distortion. It was developed in the 1930s by Edgar C. Bain and Edmund S. Davenport. To begin with, it was usually applied to steel products [1, 2, 3].

Ductile iron or spheroid graphite iron was developed during the 1940s. Ductile iron with its unique graphite morphology is a material that has tensile and impact properties sufficient for many different application (vehicle and agriculture industry, mining, pipes, and so on). In the second half of the twentieth century the austempering process began to be applied commercially to cast irons.

Austempered Ductile Iron (ADI) was first commercialized in the early 1970s but serious research in the field of ADI application was carried out at the end of the 20th and beginning of the 21st century [4].

A diagram that illustrates the Austempering process is presented in Figure 1.

The most notable difference between austempering and conventional quench and tempering is that it involves holding the workpiece at the quenching temperature for an extended period of time. The basic steps are the same whether applied to cast iron or steel and are as follows [5-7]:

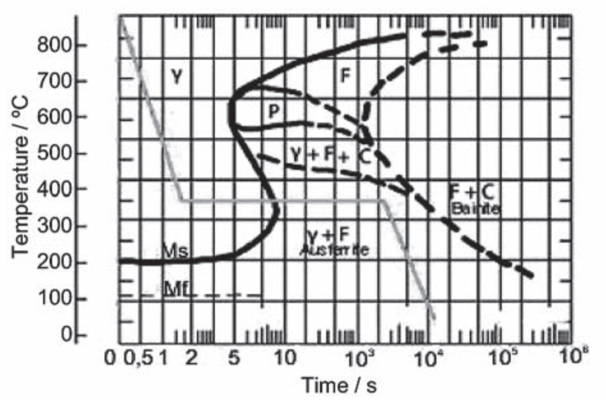

Figure 1 I-T Diagram of the Austempering Process, [1]

- Heating to a temperature to produce austenite
- Quenching rapidly to avoid the formation of pearlite to a temperature above the martensite start temperature (Ms temperature). The selected quench temperature is referred to as the austempering temperature.
- Holding at the selected austempering temperature for a time sufficient to transform the austenite to the desired end microstructure (bainite for steel or ausferrite for cast iron)
- Cooling in air to room temperature

When speaking of performance improvements, austempered materials are typically compared to conventionally quench and tempered materials with a tempered martensite microstructure. In cast irons these improvements include [2]:

- Higher tensile strength,
- Higher ductility and impact resistance for a given hardness,

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- A low distortion, repeatable dimensional response,
- Increased fatigue strength,
- Increased wear resistance for a given hardness.

EXPERIMENTAL PROCEDURE

The main idea of the experiment was to produce unalloyed ductile iron and prepare samples for heat treatment, heat treatment of the samples at different austempering temperatures, and at the end microstructure and tensile strength investigation and the comparison of the results [8]. The ductile iron base material was prepared and the chemical composition of the melt is presented in Table 1.

Table 1 **Chemical composition of the base material / wt. %**

C	Si	Mn	S	P	Mg	Ce
3,48	2,10	0,40	0,012	0,027	0,045	4,18

Malt was poured in to U blocks and after cooling the samples for heat treatments were cut. The samples were prepared according to BAS EN 10054-1/98 [9].

The main task of the investigation was to determine the influence of the austempering temperature on the tensile strength of the treated samples. According to pervious investigations and the research literature, the austempering temperature for ductile iron is in the range 250 - 420 °C. In case of this experiment nine different austempering temperatures were chosen (260 °C, 280 °C, 300 °C, 320 °C, 340 °C, 360 °C, 380 °C, 400 °C and 420 °C).

According to the plan of the experiment, ten sets of the samples were cut from the U block (nine sets for the nine different austempering temperatures and one for the tensile test of the base material). Each sample set consists of three samples (to have the average value of the tensile strength). All the other parameters of the heat treatment (austenitization time and temperature and austempering time) were the same for all the treated samples.

Prior to the heat treatment of the samples, a dilatometric investigation of the base material was conduct to set the austenitization temperature. A DIL 402/C/7 (Netzsch) dilatometer was used (heating/cooling rate: 5 / K/min). The dilatometric curve is presented in Figure 2.

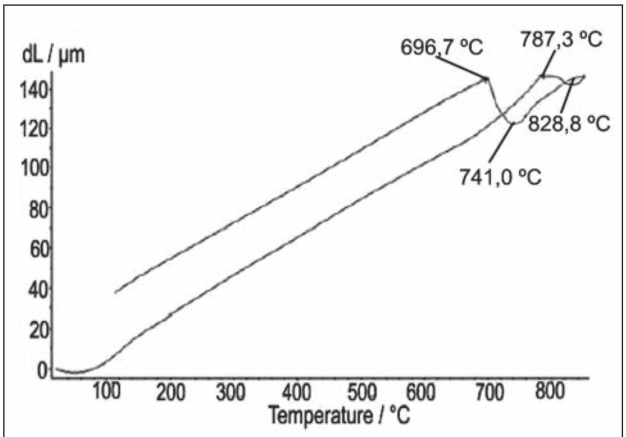

Figure 2 Dilatometric curve of the base material

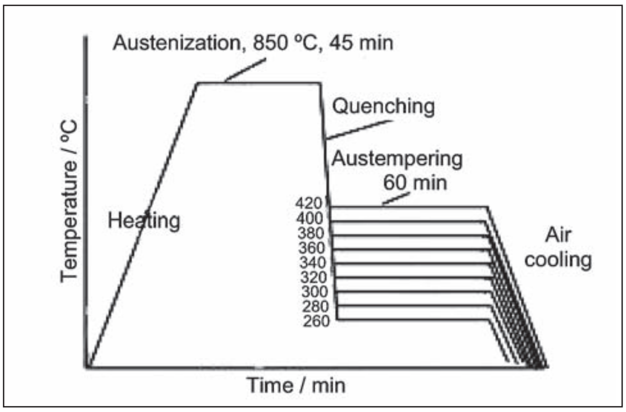

Figure 3 The heat treatment diagram

Based on the dilatometric curve shown in Figure 2, an austenitization temperature of 850 °C was set. The austenitization time (45 / min) and austempering time (60 / min) were chosen based on the geometry and thickness of the samples.

The heat treatment diagram of the samples is presented in Figure 3.

An induction furnace for austenitization and a KNO_3 salt bath for austempering were used.

The microstructure of the base and the heat treated samples were investigated using an Olympus optical microscope. For tensile strength investigation, a “Loshenhausenwerk MSU-FD-5000” universal testing machine was used.

RESULTS AND DISCCUSSION

The microstructure of the base material was a pearlitic/ferritic metallic matrix with embedded graphite nodules. The microstructure of the base material is presented in Figures 4 and 5.

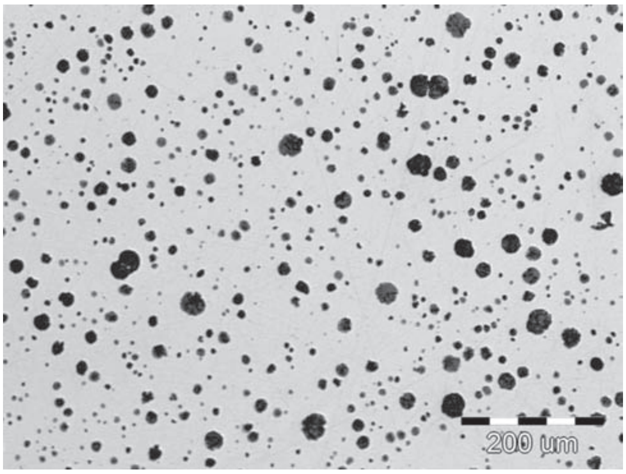

Figure 4 Microstructure of the base material, unetched, 100x

The tensile strength of the base material (the average value of the three samples) was 690 / MPa. According to BAS EN 1563:1997 the base material corresponds to the EN-GJS-600 class of ductile iron [10].

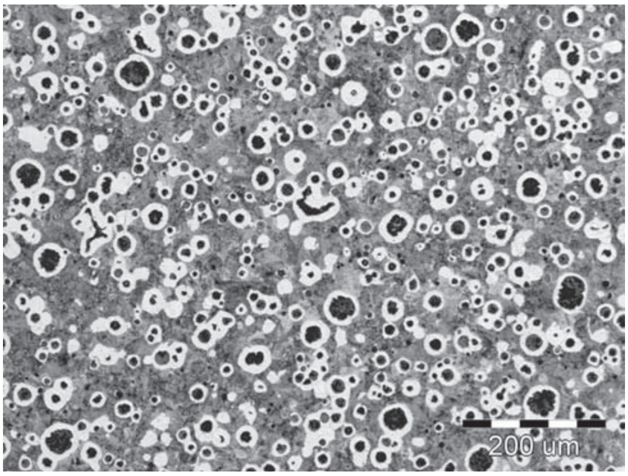

Figure 5 Microstructure of the base material, Nital etched, 100x

The results of the tensile strength investigation of the heat treated samples at the different austempering temperature are presented in Table 2 and Figure 6

Table 2 **Tensile strength of the heat treated samples (average value of three tests)**

T_a / °C	R_m / MPa			
	1st test	2nd test	3rd test	Average
260	1 364	1 361	1 368	1 364
280	1 308	1 385	1 345	1 346
300	1 300	1 305	1 316	1 307
320	1 230	1 258	1 214	1 234
340	1 084	1 369	1 112	1 188
360	970	1060	1009	1 013
380	890	920	893	901
400	697	794	840	777
420	640	792	803	745

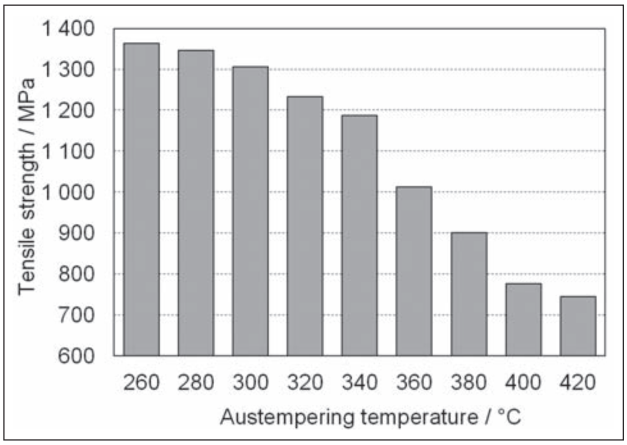

Figure 6 Tensile strength of the heat treated samples for different austempering temperatures

The microstructure of the sample after heat treatment at the corresponding austempering temperature is presented in Figures 7 to 11.

CONCLUSIONS

Summarizing the data of all the heat treatments, the microstructure and tensile testing investigation, the following can be concluded:

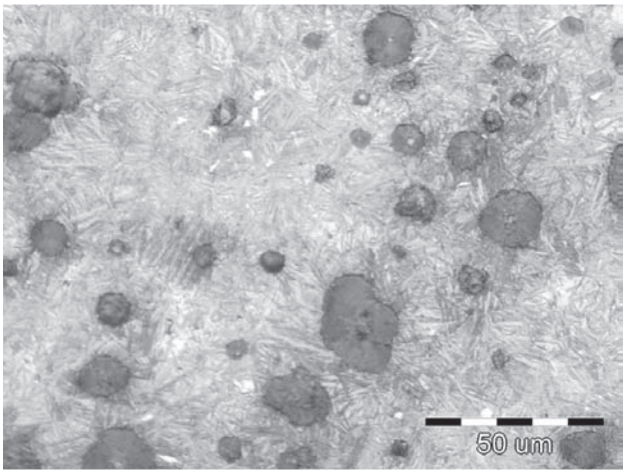

Figure 7 Microstructure of the tested sample. Austempering temperature 260 °C. Nital etched, 500X

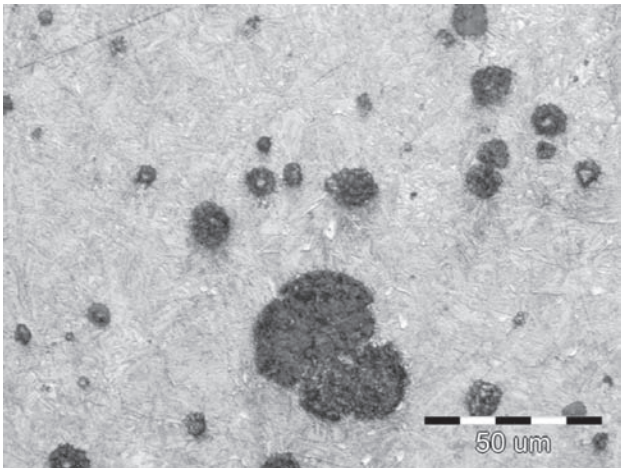

Figure 8 Microstructure of the tested sample. Austempering temperature 300 °C. Nital etched, 500X

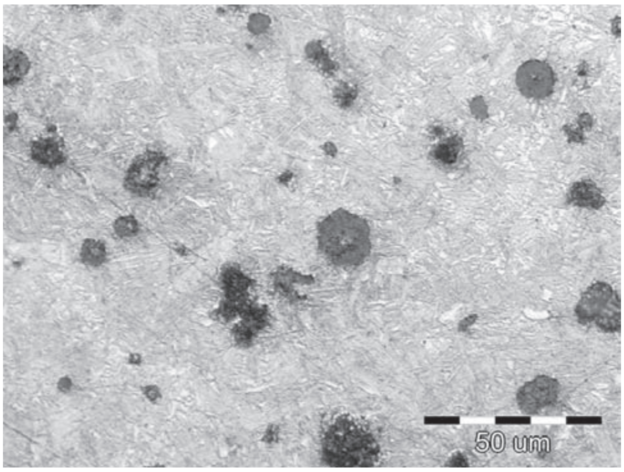

Figure 9 Microstructure of the tested sample. Austempering temperature 340 °C. Nital etched, 500X

- Heat treatment is a very powerful tool for improving the mechanical properties of the ductile iron
- The plan of the experiment was prepared correctly and the results obtained follow the research idea
- All the heat treated samples show an increase in tensile strength compared to the base material
- With the increasing austempering temperature, the tensile strength of the heat treated samples decreases

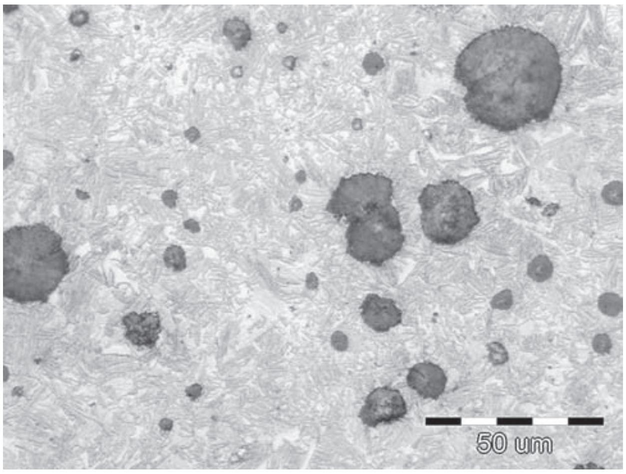

Figure 10 Microstructure of the tested sample. Austempering temperature 380 °C. Nital etched, 500X

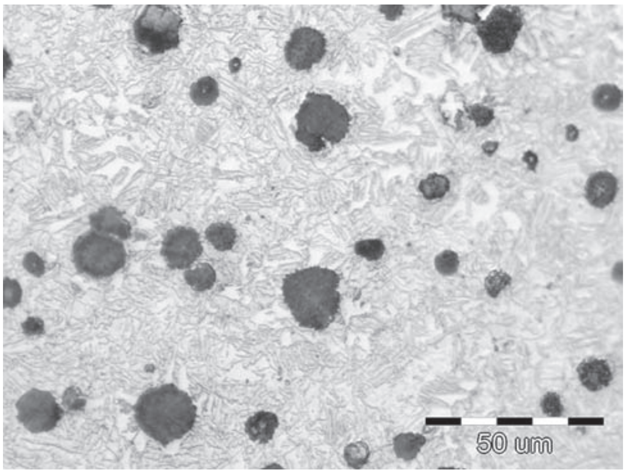

Figure 11 Microstructure of the tested sample. Austempering temperature 420 °C. Nital etched, 500X

- The microstructure of the heat treated samples consists of needle like acicular ferrite and retained austenite and was uniform at the cross section of the tested material. The size of the acicular ferrite needles increases as the austempering temperature increases.

Acknowledgements

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Note: The person responsible for English language translation: Matt Whiffen, MA. The Faculty of Philology, University of Montenegro., Podgorica, Montenegro