RELATIONSHIP OF MICROSTRUCTURAL TRANSFORMATIONS IN AUSTEMPERED NODULAR CAST WITH MICROHARDNESS VALUES

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ABSTRACT
Austempered ductile iron is the last addition to the group of ductile irons obtained by isothermal improvement of classic ductile iron. Austempered nodular cast iron has improved mechanical properties and a different matrix microstructure compared to known iron-based castings. This type of casting is obtained by isothermal improvement - austempering, whereby the resulting microstructure consists of a mixture of ausferitic (acicular) ferrite and residual, isothermally transformed, carbon-enriched, stable, austenite. Changing the austempering parameters (temperature and time of austenitization and isothermal transformation) affects the obtained ausferite microstructure, and thus the mechanical properties. The most influential parameter that affects the mechanical properties of austempered ductile iron is the isothermal transformation temperature. This paper will present the relationship between microhardness values and microstructural transformations in the material due to the effect of elevated temperatures.

1. INTRODUCTION

One of the materials whose production increases year by year is ductile iron. The properties of ductile iron can be further improved by isothermal transformation - austempering, whereby the newly produced material is called ADI material (Austempered Ductile Iron). The special properties of ADI material compared to classic ductile iron are a direct consequence of the microstructure created during austempering. The microstructure is conditioned primarily by austempering parameters (temperature and time of austenitization, and temperature and time of isothermal transformation), as well as by chemical composition.

Austempered ductile iron is the last addition to the group of ductile irons obtained by austempering classic ductile iron. Austempering of ductile iron belongs to the group of procedures that change the microstructure of the entire metallic matrix, and is carried out in order to improve the mechanical properties of the casting (strength, elongation, toughness, dynamic strength, etc.).

Austempered ductile iron has improved mechanical properties and a different matrix microstructure compared to known iron-based castings. The new microstructure of the matrix is called ausferite, Figure 1. Ausferite is obtained by heat treatment- austempering, whereby the resulting microstructure consists of a mixture of ausferitic (acicular) ferrite and residual, isothermally transformed, carbon-enriched, stable, austenite [1]. The morphology and composition of the microstructure of ADI material directly depend on the parameters of austempering (austenitization and isothermal transformation). Depending on the obtained microstructure we will have different values of mechanical properties.

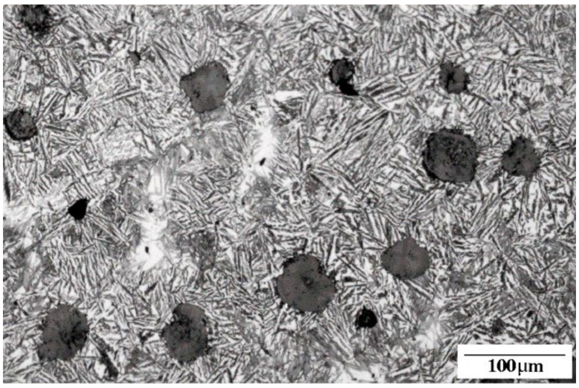

Figure 1. Microstructure of austempered ductile iron [2]

An extraordinary combination of mechanical properties primarily depends on the microstructure, i.e. on the type and amount of individual phases, as well as their morphology.
The microstructure, and thus the mechanical properties, are controlled by the correct choice of austempering parameters, chemical composition, and graphite morphology, figure 2. The most influential parameter that affects the mechanical properties of ADI material is the isothermal transformation temperature, [3]. Transformation at higher temperatures (approx. from 330 °C to 400 °C) results in high ductility and toughness, but lower strength and hardness. On the other hand, transformation at lower temperatures (approx. 250 °C to 330 °C) achieves high strength, hardness, and wear resistance, but lower toughness [4]

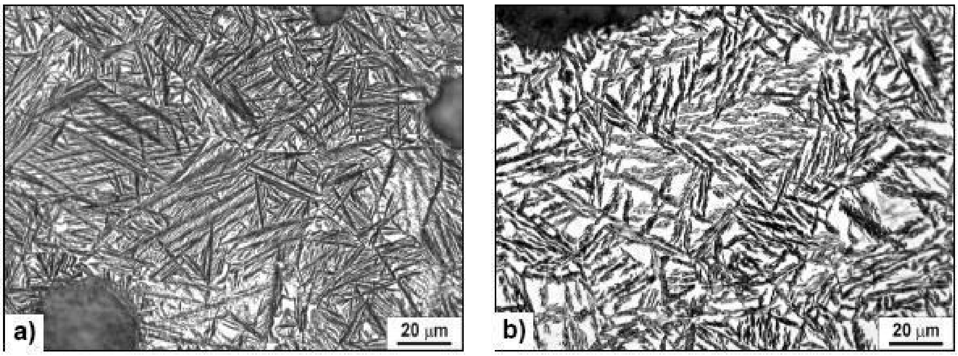

Figure 2. Ausferite microstructure of ADI material
a) the lower area of isothermal transformation; b) upper area of isothermal transformation [4]

Figure 3 shows the influence of isothermal transformation temperature on the mechanical properties of austempered ductile iron.

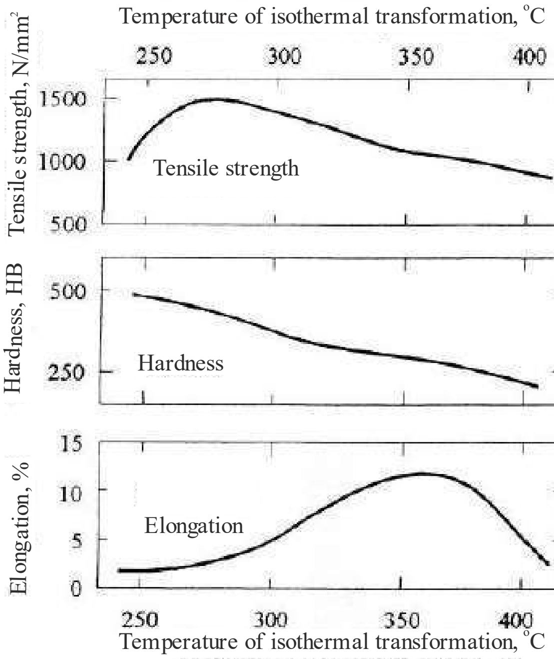

Figure 3. Influence of isothermal transformation temperature on the mechanical properties of austempered ductile iron [5]

2. PRODUCTION PROCESS OF THE AUSTEMPERED DUCTILE IRON

Within this work, ductile iron alloyed with Mo, Ni, and Cu was chosen as the starting material for the production of austempered ductile iron. This nodular casting was produced by a commercial casting process in a medium frequency induction furnace with a nominal power of 750 kW and a capacity of 1.5 t in the company "Pobjeda" Tešanj branch of the Turbe foundry.

Thermal treatments (austenitization and isothermal transformation) to obtain austempered ductile iron were carried out at the "Kemal Kapetanović" Institute in Zenica and at the Faculty of Metallurgy and Technology.

The heat treatment procedure is shown diagrammatically in Figure 4, and consists of the following steps:

- heating to austenitizing temperature 870°C,
- holding at the austenitization temperature,
- rapid cooling to the temperature of isothermal transformation 350°C,
- holding at the temperature of isothermal transformation,
- air cooling to room temperature.

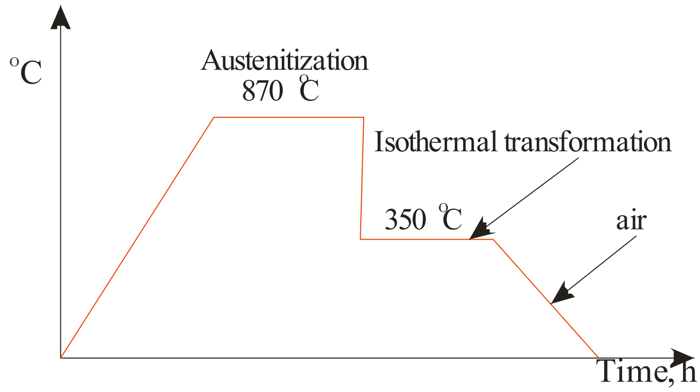

Figure 4. Thermal treatment to obtain austempered ductile iron

The initial phase of austempering is austenitization, where the initial base of ductile iron is transformed into austenite, as well as its enrichment with carbon.
The height of the austenitization temperature and holding time controls the amount of dissolved carbon in the austenite, which further affects the kinetics of transformations in the second phase of heat treatment. The austenitization temperature, which is used in the austempering of nodular cast iron castings, is in the range of 820 °C to 950 °C [6].
The second stage of the thermal treatment of the casting is the cooling of the initial austenite microstructure to the selected transformation temperature. Isothermal transformation implies a rapid transition from the austenitizing temperature to the temperature of isothermal transformation, holding at that temperature and cooling in air. The temperature interval in which transformations of the starting austenite microstructure take place is between 270°C and 400°C [7].
An ausferite microstructure of ADI material is formed by isothermal transformation. Ausferite is formed by the formation of ferrite bundles within previous austenite grains.
The medium used for the isothermal transformation of the samples was KNO_3, and the holding time in the medium was 90 minutes. In the process of formation of the final microstructure in austempered ductile iron, the temperature of isothermal transformation plays an important role. The size and shape of the ferrite phase and the amount of residual austenite largely depend on the value of the selected isothermal transformation temperature. If at the end of the technological process, one wants to obtain a casting that will have high values of tensile strength and hardness with lower values of ductile properties, it is necessary to choose lower temperatures of isothermal transformation (270 °C to 330 °C) [7].
After thermal treatment of the starting material, austempered ductile iron with the properties prescribed for this type of material was obtained.
Based on the results of dilatometric and differential thermal analysis (DTA) obtained in the framework of previous research [8], it was decided to subsequently thermally treat the ADI samples at 5 different temperatures as follows: 400 °C, 420 °C, 470 °C, 520 °C and 550 °C. The goal of the research is to show whether the change in microstructure at elevated temperatures affects the change in mechanical properties, which was monitored through the results of the microhardness test.

3. TESTING THE PROPERTIES OF THE INITIAL ADI MATERIAL AND SUBSEQUENTLY THERMALLY TREATED SAMPLES

After the final (subsequent) thermal treatments, in order to observe the behaviour of the material under conditions of elevated working temperatures, detailed tests were carried out, both on these samples and on the initial ADI material. Among other things, the tests included detailed microstructural analysis using an light microscope and microhardness testing

3.1 Analysis of the microstructure on a light microscope

Microstructure analysis was carried out in the Metallographic Laboratory of the "Kemal Kapetanović" Institute in Zenica on an Olympus PMG3 light microscope with additional equipment for image storage. The microstructure tests were carried out with the aim of determining possible microstructural transformations in the material due to the effect of elevated temperatures. Figures 5 to 10 show the microstructures of the initial austempered ductile iron and samples additionally thermally treated at appropriate temperatures.

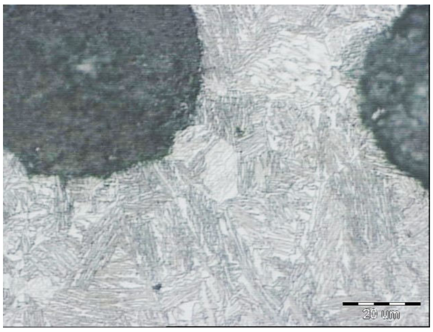

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Figure 5. Microstructure of the starting material (Austempered ductile iron)
Ausferite microstructure composed of fine acicular ferrite and residual austenite with separated carbon in the form of nodules

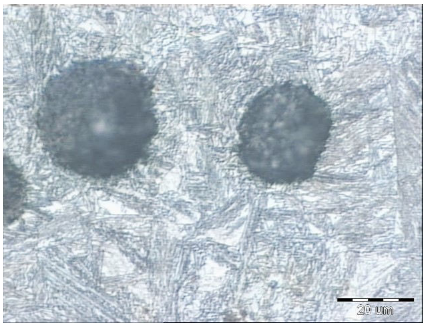

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Figure 6. Microstructure of additionally treated material (400 °C/2h)
Ausferite microstructure is composed of acicular ferrite, residual austenite, and excreted graphite nodules. A noticeable process of degradation of the initial microstructure.

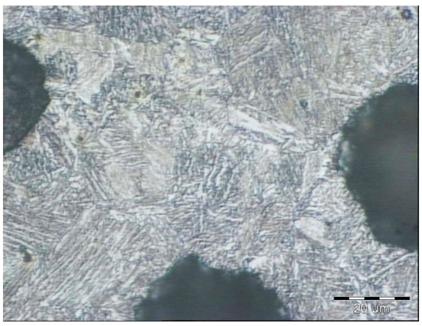

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Figure 7. Microstructure of additionally treated material (420 °C/2h)
Ausferite microstructure is composed of acicular ferrite, residual austenite, and excreted graphite nodules, with noticeable degradation of the initial microstructure.

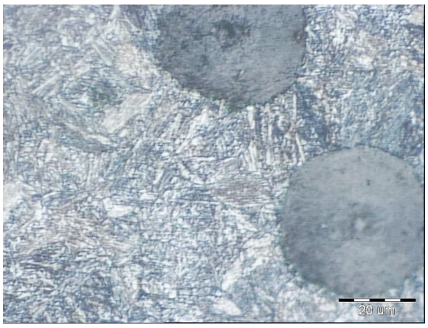

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Figure 8. Microstructure of additionally treated material (470 °C/2h)
Ausferite microstructure is composed of acicular ferrite, residual austenite, and excreted graphite nodules, with noticeable degradation of the initial microstructure

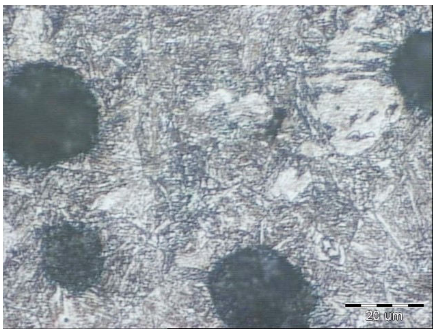

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Figure 9. Microstructure of additionally treated material (520 °C/2h)
Ausferite microstructure in traces, acicular ferrite degraded, needles broken, initial microstructure almost completely degraded.

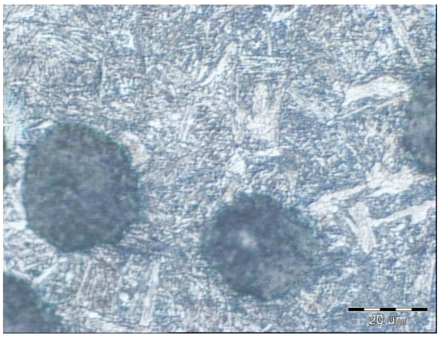

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Figure 10. Microstructure of additionally treated material (550 °C/2h)
Ausferite microstructure in traces, acicular ferrite degraded, needles broken, initial microstructure almost completely degraded.

3.2 Microhardness test

The microhardness test HV0.03 per cross-section of the samples was carried out on a ZWICK hardness and microhardness test device. The goal of this test is to determine changes in microhardness values that are related to microstructural transformations in the material due to the effect of elevated temperatures. Figure 11 shows the locations of the microhardness test by the cross-section of the sample of the initial ADI material, while Table 1 gives the individual microhardness values for this sample. The other 5 samples treated at temperatures of 400 °C, 420 °C, 470 °C, 520 °C and 550 °C were tested on the same principle. The average values of tested microhardness for all samples are given in Table 2 and Figure 12.

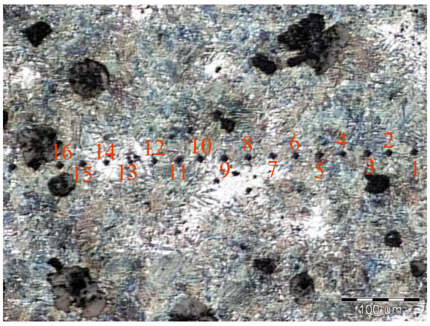

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Figure 11. Locations of HV0.03 microhardness imprints on the cross-section of the sample

Table 1. Values of microhardness HV0.03 on the sample of the initial ADI material (Average 424HV0.03)

Location	Values of microhardness HV0,03	Location	Values of microhardness HV0,03
1	386	9	329
2	386	10	329
3	386	11	530
4	481	12	460
5	421	13	530
6	371	14	505
7	421	15	443
8	421	16	386

Table 2. Average microhardness values for the samples

Sample:	ADI material	400 °C/2h	420 °C/2h	470 °C/2h	520 °C/2h	570 °C/2h
Average microhardness values HV0,03	424	474	454	677	444	394

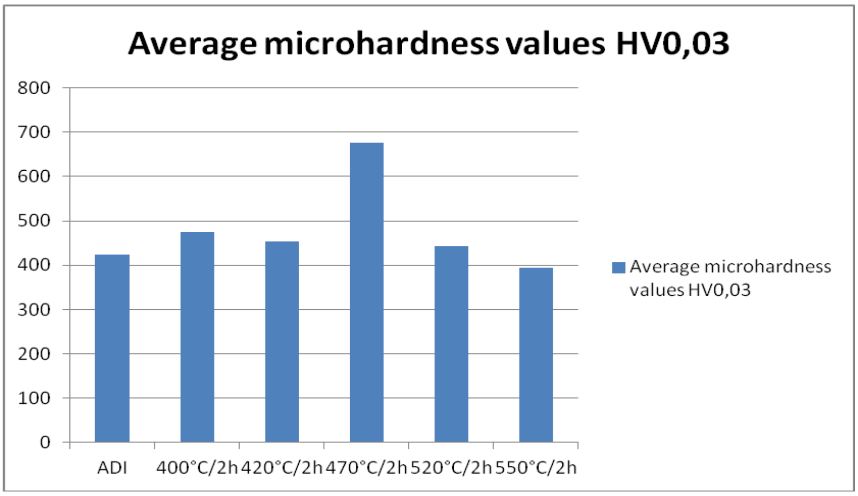

Figure 12. Graphic representation of the average values of microhardness HV0.03

4. CONCLUSION

Depending on the stability of the microstructure, i.e. the insight into the transformation of the initial ausferite microstructure when exposing the material to elevated working temperatures, one can talk about the properties of isothermal nodular cast iron at elevated temperatures.

Based on the results of earlier research, it was concluded that certain microstructural transformations occur due to the heating of isothermally improved nodular samples, which is most clearly noticeable in the temperature interval from 450 °C to 500 °C[8].

Based on this fact, an experiment was designed for these tests, and a subsequent heating regime was defined, which represents the simulation of the behaviour of austempered ductile iron at elevated temperatures.
Based on the microhardness values tested on the mentioned samples, it can be concluded that the microhardness value increased precisely in the temperature interval 450 °C to 500 °C, Figure 12. More precisely, the highest increase in the microhardness value was observed on the sample that was subsequently treated at 470 °C, which is a consequence of the microstructural transformation. So, the research confirmed that at higher temperatures the microstructure broke down into ferrite and carbide. Carbides are microconstituents that increase the value of microhardness.

5. REFERENCE

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