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EFFECT OF AUSTEMPERING TEMPERATURE ON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF UNALLOYED DUCTILE IRON

VPLIV AUSTEMPERING TEMPERATURE NA MIKROSTRUKTURO IN MEHANSKE LASTNOSTI NELEGIRANE DUKTILNE SIVE LITINE

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Austempered ductile cast iron (ADI) has emerged in the last several decades as a major engineering material. The heat-treating of the ductile cast iron produces austempered ductile iron (ADI) with an excellent combination of s trength, fracture toughness and wear resistance for a wide variety of applications in automotive, rail and heavy engineering industries.
The austempering temperature is the most important parameter in determining both the structure and the mechanical properties of unalloyed austempered ductile irons. It is varied in the range of 250-450°C. The aim of this wor k was to optimize the microstructure, and consequently the properties of ductile cast iron of composition Fe-3.48C-2.7Si (in wt.%). The analysis of the microstructure was performed by light microscopy, scanning electron microscopy, and X-ray diffr action.

Keywords: cast iron, austempered ductile iron, austempering, retained austenite.

Austemprana duktilna siva litina (ADI) je postala v nekaj zadnjih letih pomemben in`enirski materia l. To litino izdelamo s toplotno obdelavo duktilne sive litine in ima zelo dobro kombinacijo trdnosti, `ilavosti loma in odpornosti proti obrabi. Zato je primerna za uporabo v avtomobilski, `elezni{ki in te`kih strojnih industrijah.
Austempering temperatura je temeljni parameter, ki dolo~a mikrostrukturo in mehanske lastnosti aust emprane litine. Ta temperatura je v razponu od 250 do 450 °C. Cilj tega dela je bil optimiziranje mikrostrukture in la stnosti duktilne sive litine s sestavo Fe-3,48%C-2,75%Si (v ut.%). Mikrostruktura je bila analizirana z opti~no mikroskopijo, rast er elektronsko mikroskopijo in difrakcijo X `arkov.

Klju~ne besede: austemprana duktilna siva litina, austempranje, zadr`ani austenit

1 INTRODUCTION

Austempered ductile iron (ADI) is a heat-treated ductile cast iron. It has a unique acicular matrix micro - structure that consist of high-carbon austenite (γ_{hc}) and bainite (α) with graphite nodules dispersed in it. With this microstructure ADI displays remarcable mechanical and physical properties. ADI is also highly versatile respect to manufacturing. Furthermore, the manufact- uring cost of an ADI component is lower than that of plain carbon or low-alloy steels[3].

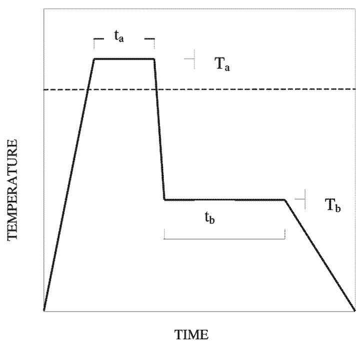

Figure 1: Schematic diagram of the austempering heat-treatment process
Slika 1: Shema austempering toplotne obdelave

Austempering is an isothermal heat-treatment process whose features are shown schematically in **Figure 1**. It consists of austenitizing the components at approximately 900°C, quenching to the appropriate temperature (250 to 500°C) and holding at this temperature for between ½ and 3 hours. During the holding period, austenite transforms isothermally to give a predominantly bainitic microstructure with varying proportions of retained austenite.

2 EXPERIMENTAL

The chemical composition of the material used in this investigation (in weight percents) is reported in **Table 1**. Tensile test bars were machined from the bottom section of the cast keel blocks 300 x 150 x 25 mm of unalloyed cast iron to avoid segregation effects, porosity, and low nodule count in the upper section.

All the specimens were initially austenitized at 900°C for 2h and then austempered in molten salt bath at different temperatures in the range of 250 to 450°C for 2h, and then finally air-cooled to room temperature. Five identical test specimens were tested from each condition and the average values are reported in **Table 2**.

Table 1: Chemical composition of the investigated unalloyed ADI (wt. %)

Tabela 1: Kemi~na sestava preiskane nelegirane ADI (ut.%)

C	Si	S	Mn	P	Cu	Ni	Cr
3.48	2.70	0.001	0.07	0.033	0.02	0.06	0.03

Table 2: Mechanical properties of unalloyed ADI

Tabela 2: Mehanske lastnosti nelegirane ADI

Austemper-ing temperature °C	Yield Strength MPa	Ultimate Tensile Strength MPa	Elongation %	Hardness HB
250	1242	1483	1.2	453
300	1165	1380	2.4	427
350	939	1082	5.1	362
400	806	1010	6.2	331
450	717	952	7.0	324

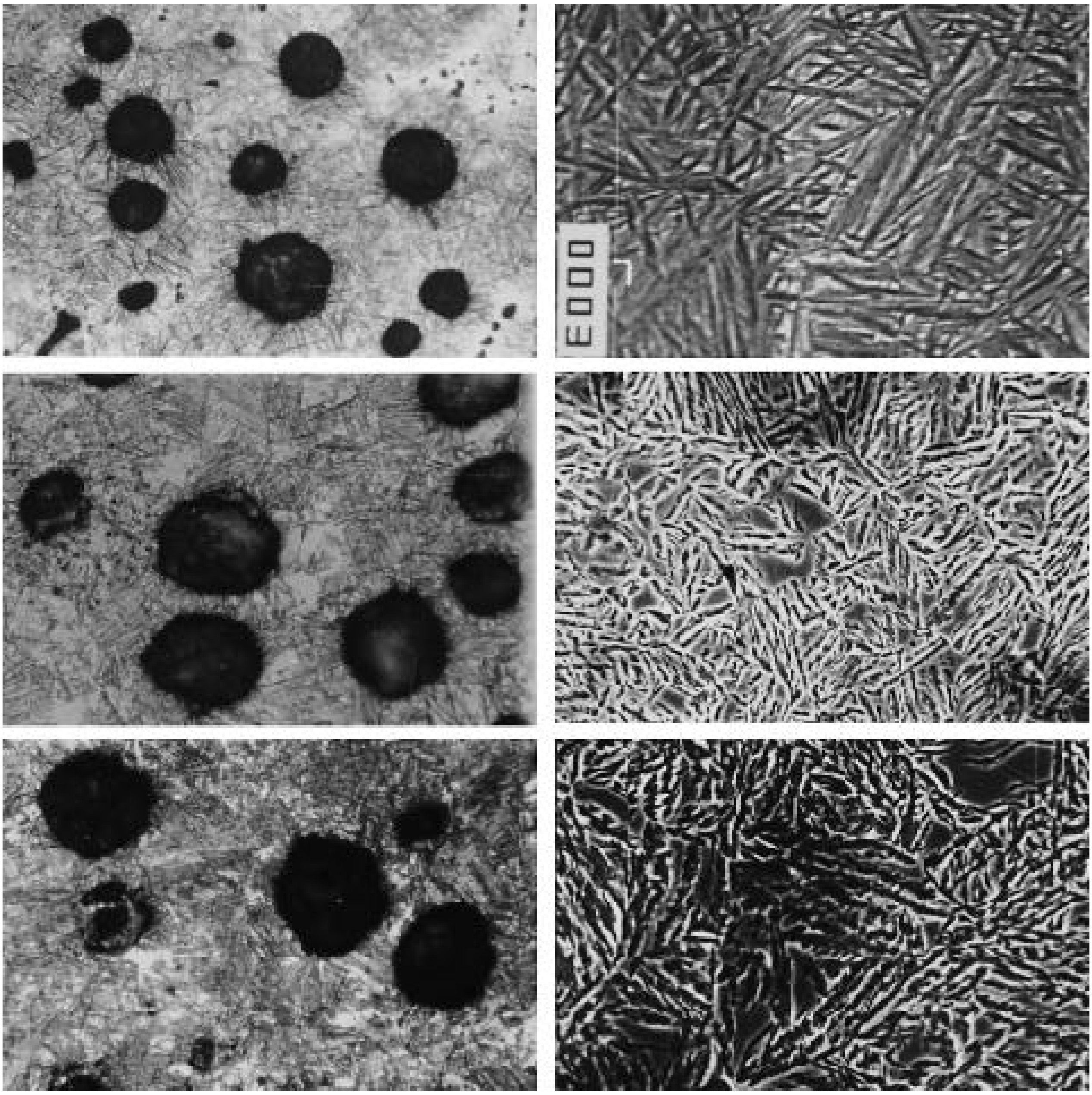

Figure 2: Microstructure of ADI; a) austempering temperature 250°C (LM x300 and SEM x1500), b) austempering temperature 350°C (LM x300 and SEM x1500), c) austempering temperature 450°C (LM x300 and SEM x1500)

Slika 2: Mikrostruktura ADI; a) temperatura austempranja 250°C (OMx300, SEMx1500); b) temperatura austempranja 350°C (OMx300, SEMx1500); c) temperatura austempranja 450°C (OMx300, SEMx1500)

Samples for microstructal analysis were taken from the tensile test specimens at positions far from the fractured area. Specimens for light and scanning microscopy were prepared by the standard metallographic technique. In addition to a qualitative analysis, a quantitative analysis using a computer image analyser was used.

The microstructures of these differently heat-treated materials are shown in **Figure 2a to 2c**, respectively. In these microstructures austenite appears as dark gray areas between adjacent bainitic platelets and graphite nodules. The volume fraction of not transformed austenite was determined with X-ray diffraction (**Figure 3**). The values of the volume fraction of phases for the heat-treated specimens are reported in **Table 3**.

Table 3: Volume share of microstructural constituents
Tabela 3: Volumski dele` konstituent mikrostrukture

Austempering temperature /°C/	Bainite %	Austenite %	Graphite %
250	75.3	10.5	14.1
300	66.4	18.0	15.5
350	65,0	21.2	14.5
400	48.3	36.6	15.1
450	45.4	39.2	15.3

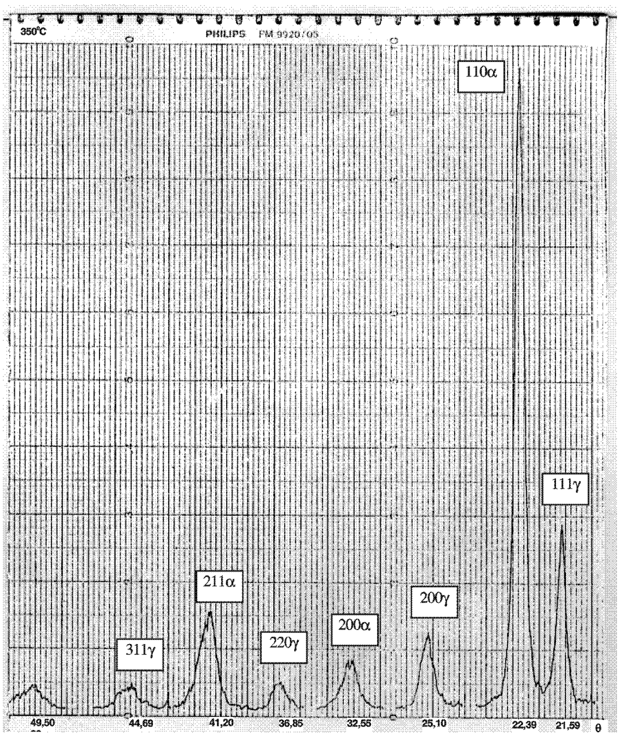

Figure 3: X-ray diffraction pattern for unalloyed austempered ductile iron
Slika 3: Difrakcijska slika X `arkov za austemprano nelegirano duktilno sivo litino

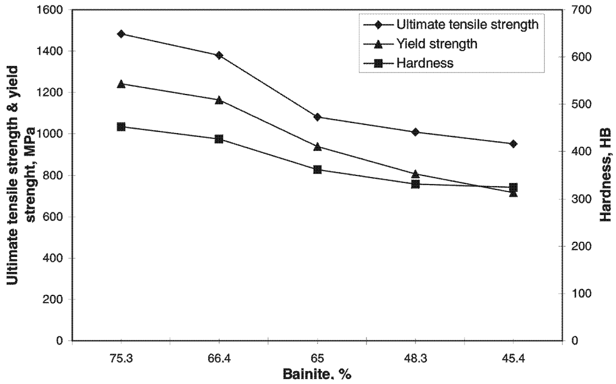

Figure 4: Influence of the volume share of bainite on hardness, yield strength and ultimate tensile strength of unalloyed austempered ductile iron
Slika 4: Vpliv volumskega dele`a bainita na trdnost, mejo plasti~nosti in natezno trdnost austemprane nelegirane duktilne sive litine

3 RESULTS AND DISCUSSION

3.1 Microstructure

The graphite spheroidisation of all tested specimens was found to be more than 90%. The graphite nodules were uniform in size and distribution with a volume fraction of 14 to 16%. An average graphite nodule size of 17m to 35m and an average count of 150mm^{-2} to 300mm^{-2} were found by image analysis. The microstructure of ADI obtained by the austempering process strongly depends on the transformation temperature. By lower austempering temperature the undercooling of austenite is greater and the diffusion rate of carbon is slow (graphite nodules are source for carbon). This results in more bainite and less austenite formation in the matrix by austempering temperatures of 250, 300 and 350°C. Moreover, these bainite platelets are rather small in size. This is clearly visible in Fig. 2a-b.

At the higher austempering temperature, the carbon diffusion rate is faster and, consequently, the growth rate of bainitic platelets is rather rapid. This results in a lower volume share of bainite and more austenite in the metal matrix, but bainitic platelets are rather coarse, as clearly visible in **Figure 2c**.

3.2 Mechanical properties

Test results reported in Table 2 show that after austempering at a lower temperature (250°C) the maximal yield and tensile strength and hardness of ADI are obtained, while austempering at a higher temperature (450°C) produces the maximal ductility of unalloyed ADI. Ductility of the unalloyed ADI increases with the increase in the austempering temperature.

In **Figure 4** hardness, yield, and ultimate tensile strength of unalloyed ADI are plotted against the volume share of bainite. It is evident that as the volume share of bainite increases, hardness, yield, and ultimate tensile strength of ADI increase. Since the graphite content is more or less the same, the above test results indicate that hardness, yield, and ultimate tensile strength of ADI decrease as the volume fraction of austenite in the matrix increases, i.e., for higher hardness, yield, and ultimate tensile strength, ADI should have more bainite and less austenite in the matrix, and should be, therefore, austempered at a lower austempering temperature. On the other hand, for higher ductility, ADI should have more austenite in the matrix and should be treated at a higher austempering temperature.

4 CONCLUSIONS

At lower austempering temperatures (250, 300 and 350°C) more bainite was nucleated while its growth rate was rather slow. It resulted in a larger volume fraction of bainite in the matrix in form of smaller bainitic platelets.

At higher austempering temperatures (400 and 450°C) less bainite was nucleated, while, its growth rate was more rapid. As a result, the matrix consisted of a smaller volume share of bainite in form of significantly coarser platelets.

Yield, tensile strength and hardness of unalloyed ADI increase with increase in volume share of bainite in the matrix, while, the ductility of ADI increases with the increase in volume fraction of austenite in the matrix.

5 REFERENCES

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