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## Highsilicone Austempered Ductile Iron

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### Abstract

Ductile iron casts with a higher silicone content were produced. The austempering process of high silicone ductile iron involving different austempering times was studied and the results presented. The results of metallographical observations and tensile strength tests were offered. The obtained results point to the fact that the silicone content which is considered as acceptable in the literature may in fact be exceeded. The issue is viewed as requiring further research.

**Keywords:** Austempered ductile iron, Silicone content, Matrix structure, Mechanical properties, Ultimate tensile strength

### 1. Introduction

Currently austempered ductile iron - ADI [1] still appears 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 such as gears, crankshafts, support wheels [16, 17], food processing [18] or even mining [19].

Obtaining high tensile strength with acceptable elongation or considerable elongation with good tensile strength is possible during a relatively simple and cheap technological process involving solution heat treatment at the temperature 815-950°C, which is followed by isothermal quenching at the temperature range of 230-400°C (Fig 1). Typical chemical composition of ADI described in the literature is located within the range: 3,0÷4,0C%, 1,5÷3,3%Si, 0,1÷1,0%Mn, P and S as low as possible and 0,03÷0,07%Mg.

According to [20] the amount of silicone above 3,5% is harmful because of the appearance of the undesirable ausferrite structure, which resides in the occurrence of specific ferrite clusters in the matrix.

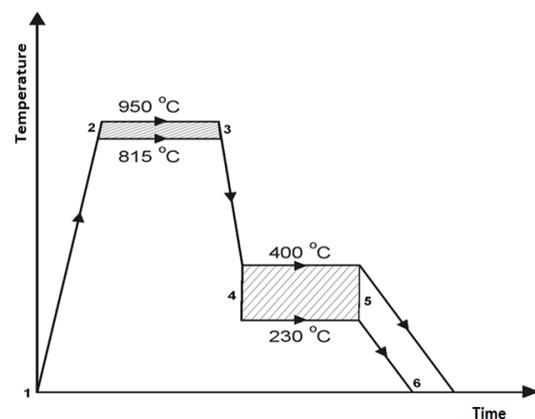


Fig. 1. ADI heat treatment process chart

In the present study the melt with the concentration of silicone higher than mentioned was considered and the preliminary research was conducted.

The goal of this paper is to discuss the results obtained for ductile cast iron subjected to a two-step austempering.

## 2. Experimental procedure

The chemical composition of the melt is shown in the table 1. Tensile specimens of 7 mm in diameter were machined from the bottom part of the Y2 blocks. Additionally specimens for hardness and metallography were cut.

Table 1.

Chemical composition and properties (as cast) of ADI with high silicone content, wt.%

C	Si	Mn	P	S	Cr	Cu	Mg	TS	YS	A <sub>5</sub>	HB
3,40	3,74	0,26	0,04	0,01	0,03	0,22	0,06	543	427	19	202

With the aim of getting a proper austenitic structure the austenitisation was conducted at the temperature 900°C for 2h. The austenitization was followed by rapid quenching. The austempering temperature was 275°C. The austempering step was performed for different time periods (30, 60 and 120 min) in a tin bath.

After heat treatment the specimens were grinded to remove the 0.1 mm thick surface layer, which we expected to be decarburized during solid solution heat treatment. The specimen were tensile tested using the ZwickRoell Z250 testing machine. For each heat treatment parameter three specimens were used. With the exception of the tensile test, Brinell hardness measurements were conducted with the hardness testing machine KP15002P. The parameters are presented in table 2.

Table 2.

Hardness testing machine KP15002P parameters

Intender	load	Time
ball 2,5 mm	187,5 kg	35 s

Microstructure observations were carried out on metallographic specimens which were prepared via conventional grinding and polishing and which were etched with 4%HNO<sub>3</sub> solution in C<sub>2</sub>H<sub>5</sub>OH. The microstructure was observed in Olympus IX-70 light microscope using different magnifications and observation modes.

## 3. Results

### 3.1. Metallography

Fig.2 presents the microstructure of ductile iron as cast. As can be seen, the microstructure of ductile iron as cast consists of nodular graphite precipitates embedded in almost pure ferrite matrix. Some amount of pearlite and a few isolated precipitations of carbides were observed at the boundaries of the eutectic grain.

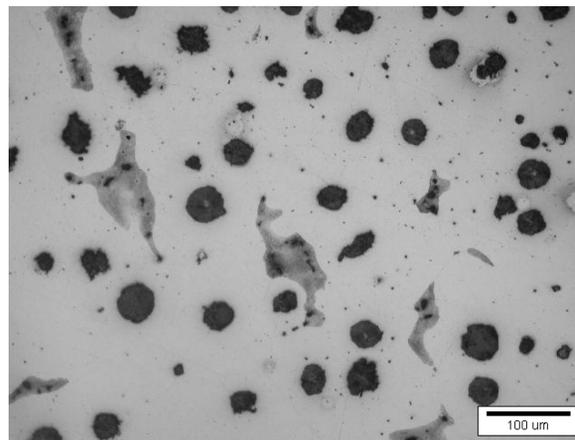
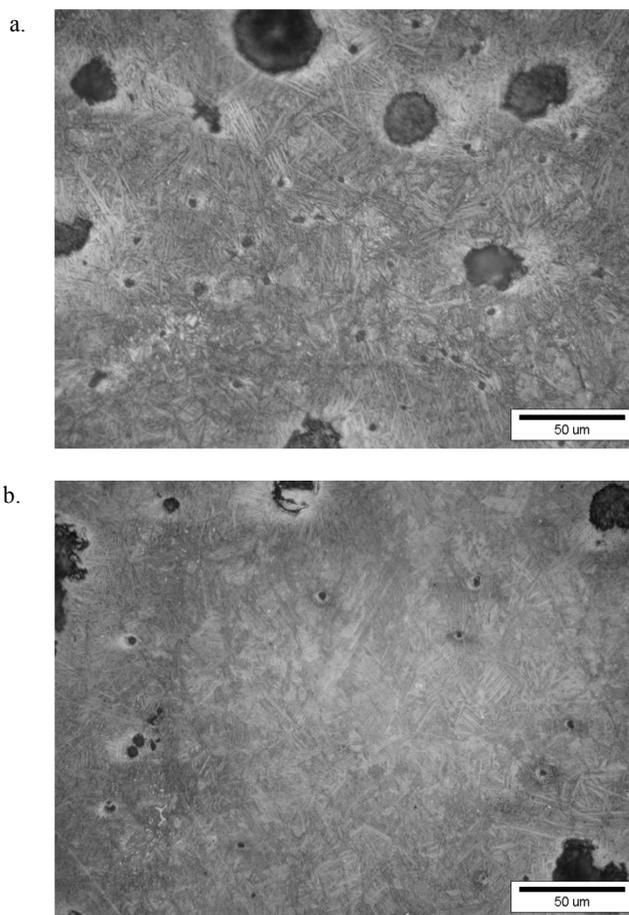


Fig. 2. The microstructure of as cast ductile iron

Fig. 3. shows the typical microstructures obtained for various austempering times.



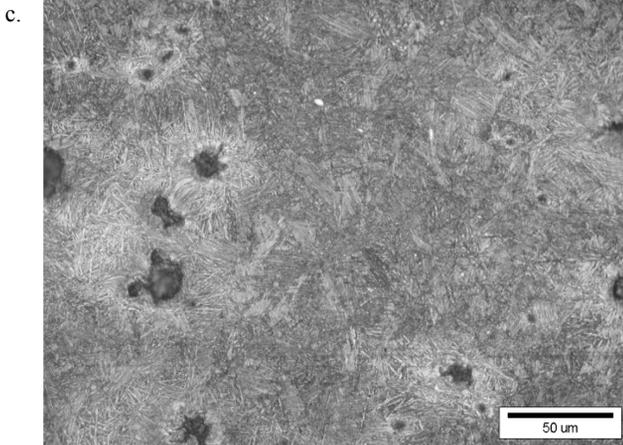


Fig. 3. The microstructure of ductile iron after: a – 60, b -90, c -120 minutes of austempering (x500)

In all micrographs the typical microstructure of ADI is observed. It appears that the amount of white areas, which represent carbon stabilized austenite, is small and decreasing with the austempering time increase. The areas of specific ferrite clusters reported by [20] are not found. The areas of austenite were observed mainly in the eutectic grain boundary Fig.4.

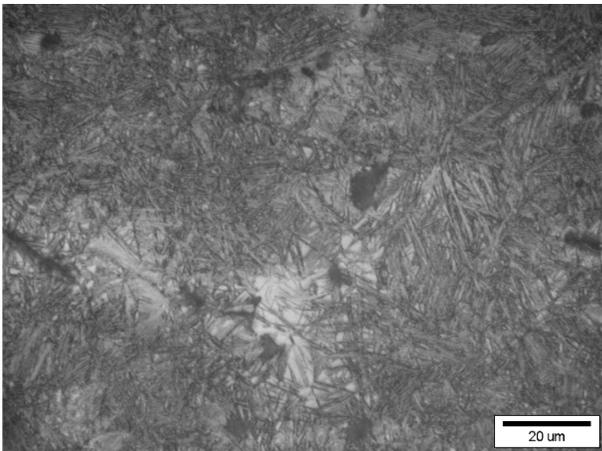


Fig. 4. The microstructure of ductile iron after 60 of austempering (x1000)

It is worth mentioning that in the eutectic grain boundary specific precipitations of carbon were observed. They were so small and close to the spherical symmetry that they certainly do not result in the reduction of the strength of the tested specimens.

### 3.2. Mechanical Properties

The graphic illustration of mechanical testing is given in Fig. 5.

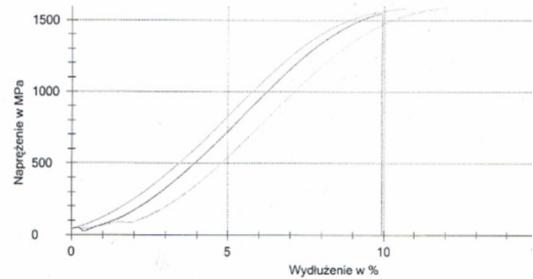


Fig. 5. Ultimate tensile strength measurement for 120 min of austempered time

For 120 minutes austempering time the ultimate tensile strength exceeded 1500 MPa. At all conditions of heat treatment the recorded elongation was bigger than 1%.

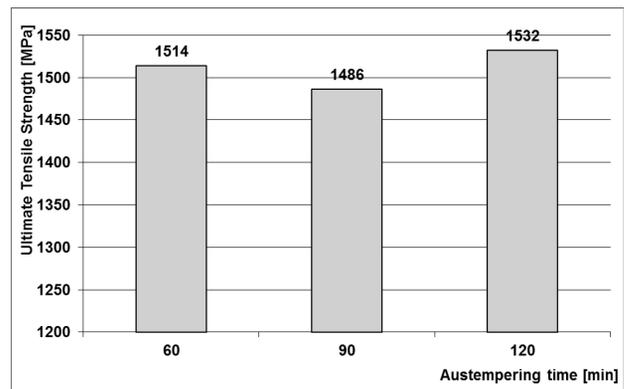


Fig. 6. Ultimate tensile strength (mean values) as a function of austempering time

Figure 7 illustrates hardness results obtained at different isothermal treatments periods.

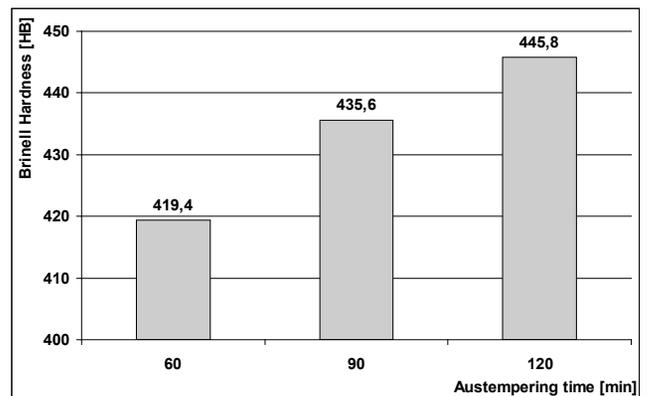


Fig. 7. Brinell hardness (mean values) as a function of austempering time

## 4. Discussion

The obtained properties of high silicon austempered ductile iron were similar to the properties obtained for standard ADI. The maximum tensile strength was observed after 120 minutes austempering, but it remained practically almost constant with the value of about 1500MPa. It seems that the strength of high silicon ADI is less sensitive to the isothermal quenching time. The hardness increases with the increase of the austempering time. The values of hardness are higher than those obtained for the standard ADI. The elongation is comparable with the standard for the received strength.

The structure consists of ferrite needles and a small amount of austenite. Areas of austenite are present at the boundaries of eutectic grain. Due to its small content, austenite must be highly supersaturated with carbon. As expected, there were no carbides or unusual clusters of ferrite in the resulting material. Elongation up to 1% suggests that martensite precipitations are possible even if their content is minimal. Further research concerning this issue is necessary.

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