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Properties and Structure of High-Silicone Austempered Ductile Iron

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Abstract

The results presented in this paper are a continuation of the previously published studies. The results of hest treatment of ductile iron with content 3,66%Si and 3,80% Si were produced. The experimental castings were subjected to austempering process for time 30, 60 and 90 minutes at temperature 300^{o}C. The mechanical properties of heat treated specimens were studied using tensile testing and hardness measurement, while microstructures were evaluated with conventional metallographic observations. It was again stated that austempering of high silicone ferritic matrix ductile iron allowed producing ADI-type cast iron with mechanical properties comparable with standard ADI.

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

1. Introduction

ADI properties depend on both the chemical composition and heat treatment parameters. While the influence of austenitizing parameters and isothermal quenching has been thoroughly studied, the publications concerning the influence of the chemical composition is much less.

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 the information included in ASTM the silicone is one of the most important elements in ADI. It promotes graphite formation during solidification of cast iron and increase the eutectoid transformation temperature. Moreover it decreases the solubility of carbon in austenite. Silicone content inhibits the formation of carbides in the form of both the perlite and bainite.

According to Myszka at all [1] the amount of silicone above 3,5% is harmful because it promotes the undesirable ausferrite microstructure, which resides in the occurrence of specific ferrite clusters in the matrix. The parameters of austempering process depends on the results which would like to be obtained and they are not normalized. Typical process involve solution heat treatment at the temperature 815-950^{o}C, which is followed by isothermal quenching at the temperature range of 230-400^{o}C[2]. According to ASTM 897-90, ADI is classified from 800 up to 1600MPa [3]. Larker [4] patented the method of manufacturing of high silicon ADI containing 3,35-4,60% Si. As a result of austenitizing at temperatures above 910^{o}C and isothermal quenching at a temperature of 250-380^{o}C he obtained the casting with ultimate tensile strength around 900MPa and elongation at least 9%. The goal of this paper is to present the results obtained for ductile cast iron with content of 3,66% and 3,80%Si austenitised 120 minutes at temperature 900^{o}C and then austempered various time at temperature 300^{o}C. Austenitizing temperature and time were chosen so that on the one hand to ensure maximum saturation of austenite with carbon on the other to prevent excessive growth of austenite grains. The presented results are a continuation of our previously published studies [5].

2. Experimental procedure

The chemical composition of test samples is shown in table 1. The specimens for studies were cut from the bottom part of the Y2 type castings. Then the sample for tensile tests, hardness measurements and microstructure observations were prepared. The first one were machined as rods with diameter 7mm.

Table 1.
Chemical composition of ADI with high silicone content

No	C	**Si**	Mn	P	S	Cr	Cu	Mg
Melt 1	3,27	**3,66**	0,28	0,041	0,008	0,021	0,229	0,059
Melt 2	3,25	**3,80**	0,32	0,031	0,012	0,026	0,260	0,056

All samples were 2h austenitised at the temperature 900˚C. The austenitization was followed by rapid quenching. The isothermal quenching was carried out in the liquid tin bath of temperature 300^{o}C. Process time was varied and ranged 30, 60 and 90 min. For each heat treatment parameter three specimens were used. In order to remove the decarburized layer samples were grinded to remove the 0.1mm thick surface layer. The studies included: tensile test using the ZwickRoell Z250 testing machine, Brinell hardness measurement with the hardness testing machine KP15002P and metallographic observations in Olympus IX-70 light microscope using different magnifications and observation modes. Metallographic observations were carried out on samples prepared in a conventional manner by grinding, polishing and etching with 4%HNO_3 solution in C_2H_5OH.

3. Results

3.1. Mechanical Properties

The results of tensile strength experiment are show in fig. 1 and 2. The first of them (fig. 1) present the changes of 0,2% offset yield strength and the second (fig. 2) ultimate tensile strength as a function of austempering time at the temperature 300^{o}C. It is visible from fig. 1 that in case of both specimens, the proof stress and tensile strength increase with austempering time. There are only very small differences between them. First, the "incipient" tensile strength of higher Si content ADI is 50MP higher then ADI with lover Si concentration. The second difference is manifested by a little less intensive increase of R_m in case of ADI with 3,80%Si compare to ADI with 3,66%Si, although the tensile strength of both type ADI is almost the same after 90 minutes austempering time.
In fig. 3 the results of hardness measurements carried out for the specimens isothermally heat treated at the temperature 300^{o}C for different time. If compare the course of hardness changes with time it can be stated that, there is no substantial difference between them. The hardness of ductile iron containing 3,66%Si and 3,80%Si is comparable and almost constant in time regime. Relative small difference is observed for 90 minutes austempering where some HB increase and decrease is observed for less and more Si content respectively (fig. 3)

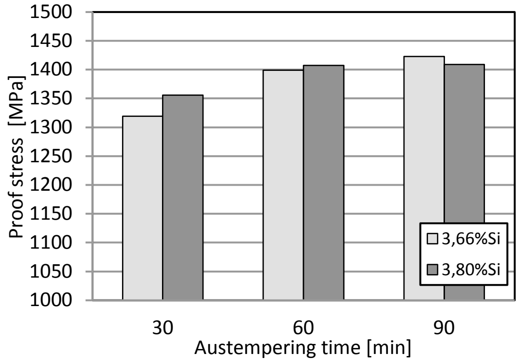

Fig. 1. The mean values of proof stress of ADI iron obtained for different austempering time

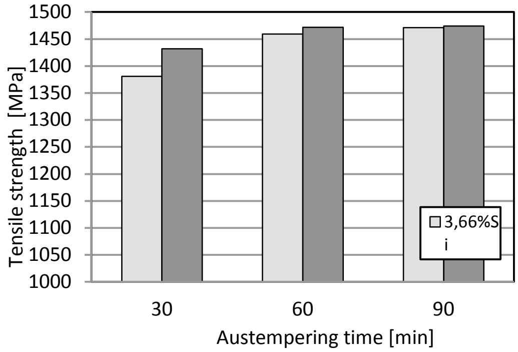

Fig. 2. The mean values of tensile strength of ADI iron obtained for different austempering time

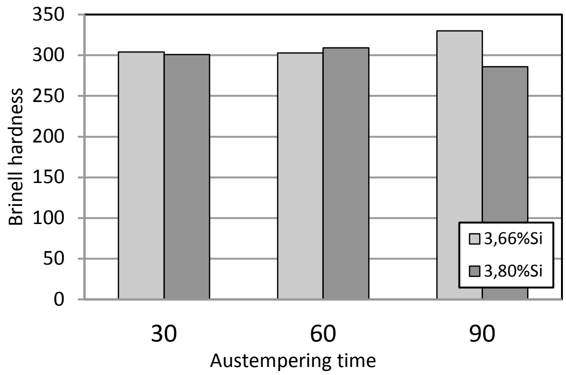

Fig. 3. The mean values of Brinell hardness of ADI obtained for different of austempering time

3.2 Metallography

Fig. 4 presents the microstructure of ductile iron as cast. It consists of graphite nodules embedded in ferrite matrix. Some amount of perlite and a few isolated carbides were observed at the boundaries of the eutectic cells. The microstructure of heat treated ductile iron with 3,66%Si and 3,80%Si is given in figs. 5 and 6 respectively.

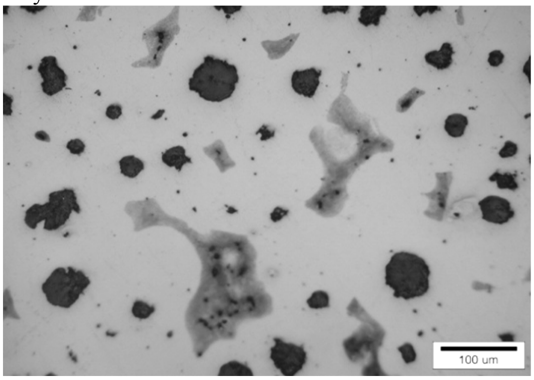

Fig. 4. The microstructure of as cast ductile iron

a)

b)

c)

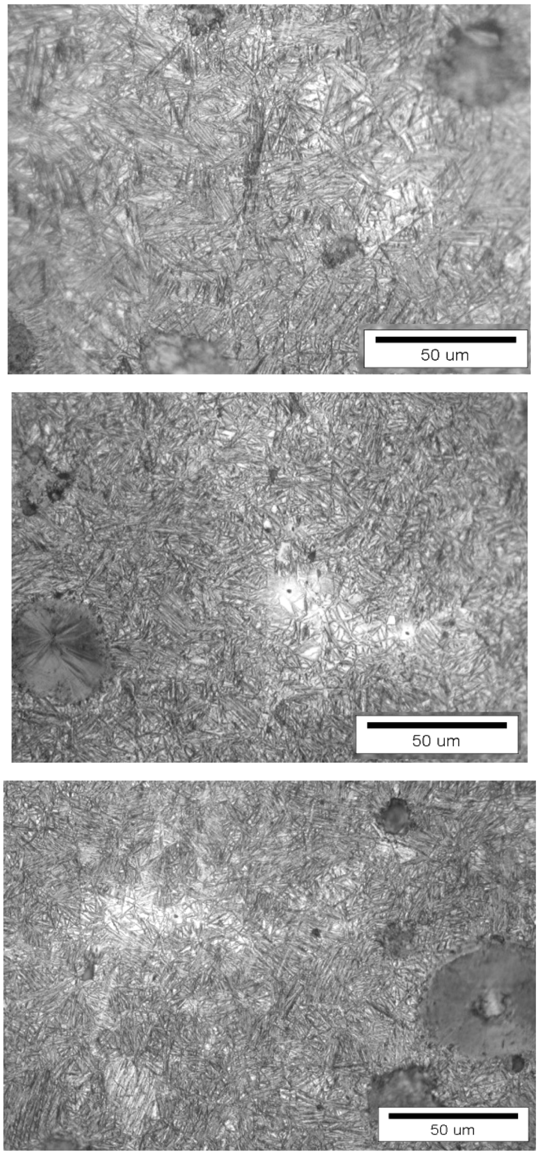

Fig. 5. The microstructure of ADI with containing 3,66% Si after austempering: a – 30, b - 60 and c - 90 minutes (x500)

The micrographs presented in fig. 5 shows the microstructures characteristic for ADI, which really do not change with austempering time. Metallic matrix is a mixture of very fine needles of bainitic ferrite in austenite background. The content of the austenite, represented by white areas, is very small. It occurs mainly at eutectic cell boundaries.

The microstructure of ductile iron containing 3,80%Si presented in fig. 6 is also typical for ADI.

a)

b)

c)

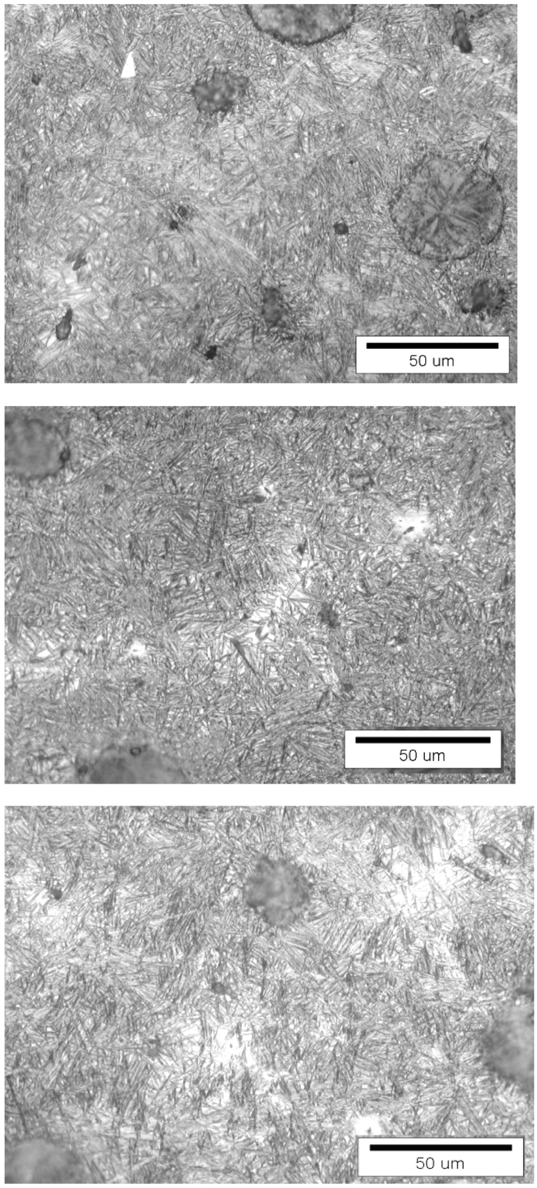

Fig. 6. The microstructure of ADI with containing 3,80% Si after austempering: a – 30, b - 60 and c - 90 minutes (x500)

Qualitative comparison of the microstructures showed in fig. 5 and fig. 6 did not discovered difference between them. In both and microstructures consists of fine and thin needles of ferrite with relative small proportion of austenite. The absence of martensite would be noted although in some places carbides (e.g. fig. 6a) were identified. The observations at double magnification did not allowed for identifying any reasonable difference between the constituents of metallic matrix (fig. 7). In both specimen the length and the width of ferrite needles is approximately 20μm and 1μm respectively.

a) b)

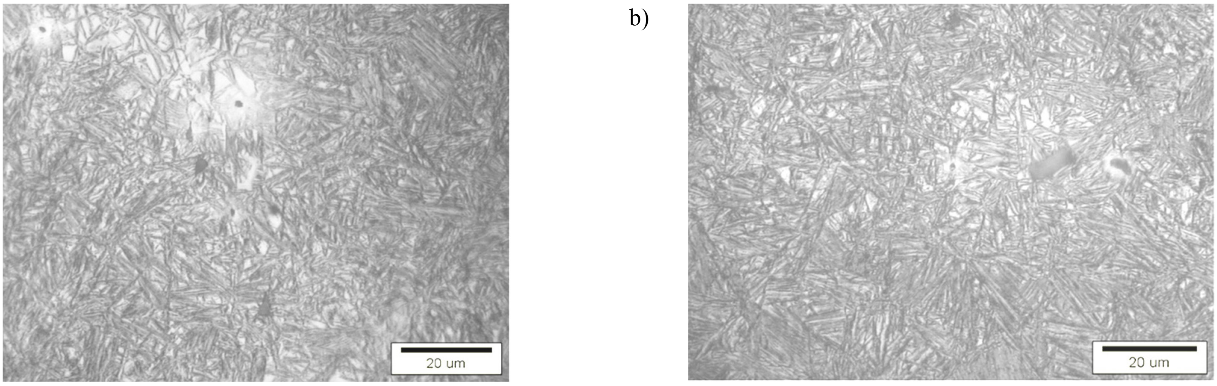

Fig. 7. The microstructure of ADI austempered 60 min. at the temperature 300°C containing: a - 3,66% Si and b - 3,80%Si observed at magnification x1000

4. Summary

The results given above confirmed our earlier statement that the heat treatment consisting of austenitization and isothermal quenching used for ADI manufacturing may be applied either for high silicone ferritic matrix ductile iron. In case of ductile iron with 3,66 and 3,80% silicon isothermal quenching for 30, 60 and 90 minutes at temperature 300°C lead to formation of metallic matrix consisting of very fine ferrite needles with relative small amount of austenite with some very tiny carbides. The tensile and proof strength of such ADI are comparable with these which can be found in ASTM standard. Although, some scattering of values concerning elongation was observed in tensile experiment, the mean values are also comparable with these for "conventional" ADI with the same tensile strength. It is very well known, that high silicon content ferritic matrix cast iron are less convenient because need more time to assure homogeneity of austenite during high temperature annealing. On the other ferritic matrix is very attractive from technological point of view because it decreases total shrinkage either during solidification and cooling to the room temperature.

There is one question more concerning impact resistance and especially ductile to brittle transition temperature -T_{DBT}. According to the literature [6] 1% increase in silicon content increase of this temperature even of 82°C.

Taking this into account the authors decided to perform experiment where the alloys being studied will be subjected impact loading at different value of temperature to evaluate value of T_{DBT}.

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