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THE INFLUENCE OF ISOTHERMAL QUENCHING ON THE EFFECTS OF THERMOMECHANICAL TREATMENT OF SPHEROIDAL CAST IRON

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Abstract

Spheroidal cast iron was treated thermomechanically both in high as well as low temperature. The two temperatures we adopted for isothermal quenching were 370° and 300° C. Plastic deformation was obtained by rolling with 25% deformation. Testing was conducted on flat samples used for stretching with the thickness of 4mm. We determined the R_m *tensile strength,* $R_{p0,2}$ *proof stress, A elongation, and HRC hardness. A microstructure test (LM, SEM), and X-ray diffraction test were conducted. We found significant positive impact of thermomechanical treatment on the structural characteristics and properties of cast iron, particularly with upper ausferrite present.*

Keywords: *spheroidal cast iron, thermomechanical treatment, structure, mechanical properties*

1. Introduction

Merging thermal and mechanical treatments makes it possible to effectively increase strength properties of iron-carbon alloys. It is in fact the only treatment with the use of which it is possible to increase strength without detriment, and frequently even with an increase, to plasticity [1]. At present, interest in thermomechanical treatment of spheroidal cast iron is growing, which can be seen in the ever higher number of studies published on this topic [2-7,9].

Particularly interesting is thermomechanical treatment (OCP) of spheroidal cast iron which undergoes isothermal treatment to obtain the AADI cast iron (Ausforming Austempered Ductile Iron). The authors of [2] used rolling and isothermal quenching of spheroidal cast iron to obtain higher tensile strength, yield point and elongation as compared to the ADI cast iron (Austempered Ductile Iron).

In this study, we obtained AADI cast iron through low- or high-temperature thermomechanical treatment. We adopted two temperature values for isothermal quenching 300° or 370° C, with constant deformation value of 25%. Our objective was to obtain either lower (300° C) or upper (370° C) ausferrite structure from undercooled austenite with plastic deformation. We compared the properties of cast iron after thermomechanical treatment with the properties of cast iron having undergone only thermal treatment (OC).

2. Material, Schedule and Test Methods

In the study, we used spheroidal low-copper cast iron with the chemical content as seen in Table 1.

Table 1. Chemical content of cast iron, % of mass

Element	**C**	**Si**	**Mn**	**P**	**S**	**Cr**	**Cu**	**Mg**
% of mass	3.76	3.07	0.35	0.07	0.02	0.04	0.48	0.06

The cast iron has been classified as grade EN-GJS-600-03. Its structure can be seen in Figure 1.

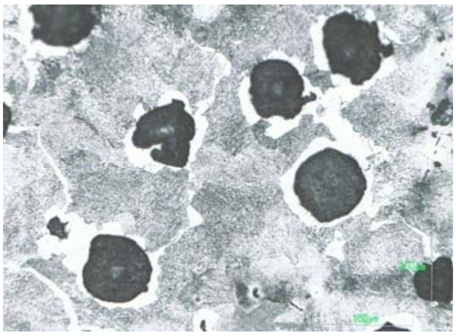

Figure 1. Cast iron microstructure in the as-cast condition, magnified 250x, times, nital edged

We cast YII samples in green-sand moulds. From the cuboid part of the wedge, we cut flat samples to be stretched, with the thickness of 4mm, measurement section width of 10mm, and measurement section length of 70mm. The samples were then treated as shown in Figure 2. The 25% cold work along the sample thickness was created through rolling on a rolling mill with plain-bodied rolls having the diameter of 95mm. Cast iron samples were austenitized in a chamber furnace, and quenched isothermally in a bath furnace with SO140 saltpetre.

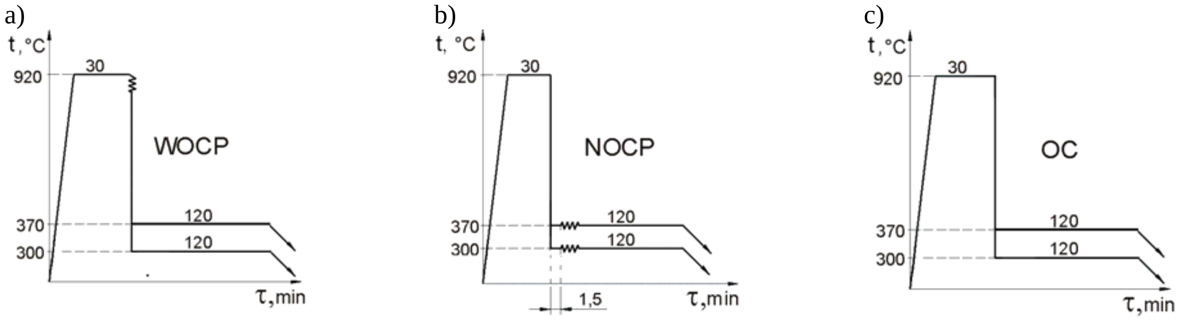

Figure 2. Spheroidal cast iron treatment diagram:
a) high-temperature thermomechanical treatment (WOCP),
b) low-temperature thermomechanical treatment (NOCP),
c) isothermal heat treatment (OC)

The strength testing was conducted on an INSTRON 8501 machine. Using typical tensile tests (PN-EN ISO 6892-1:2010), we established the values of the $Rp_{0,2}$ yield point, Rm tensile strength, and A relative elongation. Microscopic examinations were conducted on microsections etched with 2% HNO_3 solution. We used optical microscopy (NU2 microscope) or scanning microscopy (JSM 5600 microscopy).

X-ray diffraction testing was conducted on a DRON diffractometer. We used iron-filtered radiation from a cobalt anode lamp. Based on diffractogramms, we determined the type and lattice parameters of phases present in a cast iron matrix. Austenite content was established by direct comparison [10].

Carbon content in austenite was calculated based on the lattice parameter according to the relationship cited by Ogi K. et al. [8]:

$$C_{\gamma} = \frac{a_{\gamma} - 0{,}35621}{0{,}00441} \qquad (1)$$

where:
C_{γ} – carbon content in austenite, % of mass;
a_{γ} – austenite lattice parameter, nm.

The value of the austenite lattice parameter was calculated from the following formula:

$$a = \frac{\lambda}{2\sin\Theta}\sqrt{h^2 + k^2 + l^2} \qquad (2)$$

where:
λ – $Co_{K\alpha 1,2}$ wave equal to 0.179021nm;
θ – diffraction angle, °;
h,k,l – Miller plane indices.

The austenite lattice parameter was determined based on angular line location {111}, whereas the ferrite lattice parameter – based on angular line location in relation to the planes {110}.

3. Test Results and Their Analysis

The results of the static tensile and hardness tests are shown in Table 2. The tensile test results are the mean from three measurements, whereas the hardness test was conducted nine times on each sample. We set confidence interval for the mean values with $1-\alpha = 0.95$.

Table 2. Mechanical properties of cast iron depending on the type of treatment and isothermal quenching temperature

Isothermal quenching temperature, t, °C	Type of treatment	$Rp_{0,2}$, MPa	Rm, MPa	A, %	Hardness, HRC
370	WOCP	808 ±18	1112 ±26	5.7 ±0.3	38.7 ±0.6
	NOCP	1080 ±23	1252 ±19	2.5 ±0.2	43.1 ±1.1
	OC	828 ±28	1072 ±33	5.1 ±0.2	37.0 ±0.8
300	WOCP	1001 ±29	1199 ±22	2.9 ±0.2	42.5 ±1.1
	NOCP	-	893 ±38	0.4 ±0.3	48.9 ±1.6
	OC	752 ±32	1381 ±36	6.0 ±0.4	46.2 ±1.1

X-ray diffraction results are shown in Table 3.

Table 3. X-Ray diffraction results

Isothermal quenching temperature, t, °C	Type of treatment	Phase composition*	a_{γ},$^{1)}$ nm	C_{γ},$^{2)}$ % mas.	v_{γ},$^{3)}$ % obj.	a_{α},$^{4)}$ nm
370	WOCP	F+A+P	0.36217	1.35	38.1	0.28590
	NOCP	F+A	0.36264	1.46	47.0	0.28621
	OC	F+A	0.36264	1.46	30.1	0.28515
300	WOCP	F+A	0.36219	1.36	25.5	0.28585
	NOCP	F+A+M	0.36287	1.51	30.1	0.28607
	OC	F+A	0.36233	1.39	16.7	0.28607

* F - ferrite, A – austenite, P – pearlite, M – martensite
1) austenite lattice parameter, 2) carbon content in austenite, 3) volumetric percentage of austenite, 4) ferrite lattice parameter

The microstructure of cast iron quenched isothermally at 370°C is shown in Figure 3.

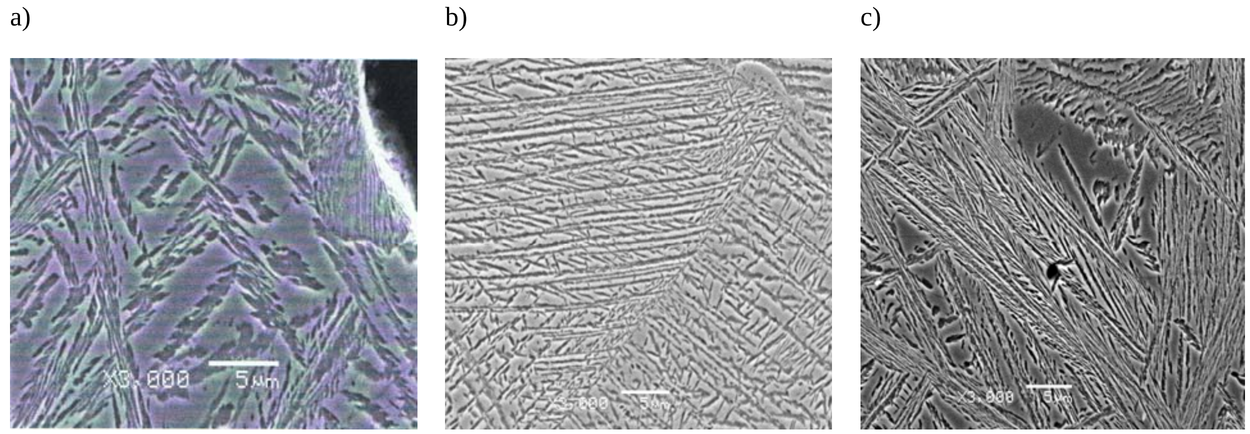

Figure 3. The microstructure of cast iron quenched isothermally at 370°C, magnified 3000x times, nital etched a) WOCP; b) NOCP; c) OC

The microstructure of cast iron quenched isothermally at 300°C is shown in Figure 4.

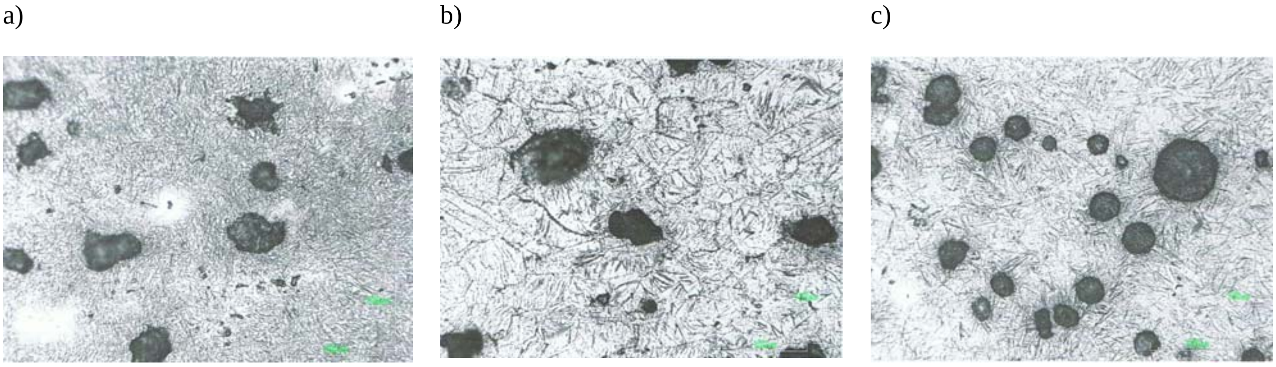

Figure 4. The microstructure of cast iron quenched isothermally at 300° C, magnified 250x times, nital etched a) WOCP; b) NOCP; c) OC

In the case of isothermal quenching at 370°C (upper ausferrite), any treatment (WOCP, NOCP, OC) increases strength two times as compared to cast iron in as-cast condition. High-temperature thermomechanical treatment causes slight increase in tensile strength and plasticity as compared to cast iron which is not treated mechanically (OC) (Table 2). The relatively small WOCP effect occurs due to the presence of some pearlite in the structure beside ausferrite (Figure 3a). Sole presence of upper ausferrite could not be achieved because of low hardening capability of cast iron. Hence, for WOCP, alloy cast iron should be used, for instance with copper or nickel content. Low-temperature thermomechanical treatment leads to the increase of strength indices (Rm = 1250MPa, $Rp_{0,2}$ = 1080MPa) as well as hardness (43HRC). Plasticity, however, is lowered. Relative elongation is 2.5%. NOCP treatment influences ausferrite morphology. Fibre orientation and the decrease of distance between ausferrite lines can be observed (Figure 3b). Example X-ray diffractogramms of cast iron after low-temperature thermomechanical treatment (NOCP) are shown in Figure 5.

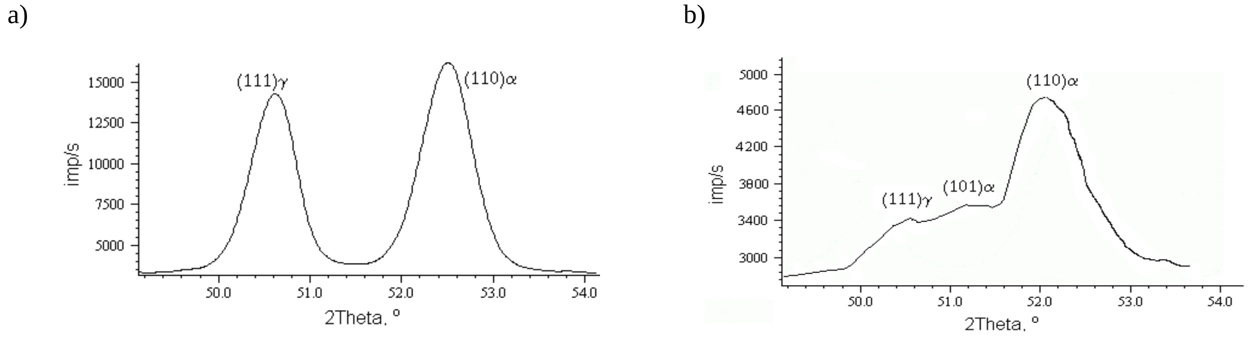

Figure 5. Cast iron diffractogramm after NOCP, quenched isothermally at: a) 370 °C, b) 300 °C

X-ray diffraction tests revealed that thermomechanical treatment increases austenite content as compared to cast iron undergoing only thermal treatment. Particularly high austenite content (47%) is present in cast iron undergoing NOCP.

With low-temperature thermomechanical treatment at 300°C, the objective will not be met (due to very low elongation and tensile strength). Obtained results can be explained by the presence of martensite in the structure (Figure 5b). Generally, it can be concluded that strength properties and hardness are higher in the case of quenching at 300°C, but plasticity is higher in the case of quenching at 370°C. Higher plasticity of cast iron at 370°C is related to higher content of austenite (Table 3) and ausferrite morphology (Figures 3 and 4).

4. Conclusions

- High-temperature thermomechanical treatment with isothermal transformation at 370°C increases plasticity but lowers strength properties of cast iron as compared to 300°C;
- Low-temperature thermomechanical treatment with isothermal transformation at 370°C can be used to obtain grade EN-GJS-1200-2 of cast iron. NOCP at 300°C leads to martensite transformation in cast iron, which causes its premature brittle cracking;
- Favourable impact of thermomechanical treatment as compared to only thermal treatment occurs in isothermally quenched cast iron at 370°C;
- Introducing cold work during thermomechanical treatment results in increased content of stable high-carbon austenite, as compared to cast iron without any cold work.

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