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Influence of gradual austenitizing on chosen properties of ADI

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Abstract

Ferritic ductile cast iron was quench-hardened with the isothermal transformation in the range of temperatures 400÷300 ^{0}C, in the range of time 7,5÷240 min. Soaking before the transformation was gradual. Nominal austenitizing temperature t_γ = 950 ^{0}C, and then there appeared cooling to $t_{\gamma'}$ = 850 or 800 ^{0}C. Heat treatment was performed with the usage of specimens for the impact strength test, and after that hardness was measured and microstructure analyzed. Test results were used to elaborate mathematical equations and to make three-dimensional charts with the usage of STATISTICA and EXCEL software. It was stated, that austenitizing temperature and conditions of the isothermal transformation influence on hardness and impact strength of ADI. On the base of hardness and impact strength it can be stated that as a result of gradual austenitizing of specimens there was obtained ADI corresponding to grades of ASTM 897 (850/550/10) Grade 1, (1050/700/7) Grade 2 and (1200/850/4) Grade 3.

Keywords: Gradual austenitizing; Isothermal transformation; Hardness; Impact strength; ADI

1. Introduction

In technology of high quality grades of the ductile cast iron microstructure of the matrix, consisting of austenite and ferrite, is essential [1-3].

Producing castings from the ADI cast iron, there is applied quench hardening with the isothermal transformation in order to create high-carbon austenite and ferrite saturated with carbon in the matrix. Such a constant of microstructure is called ausferrite, and the process of the isothermal transformation of precooled austenite is called ausferritising [4-6].

Austenitising during quench hardening, consisting in heating in temperature higher than Ac_1, has to homogenize the metal matrix and enrich austenite with carbon. During heating of the cast iron to austenite carbon atoms, coming from emissions of graphite, diffuse.

The metal matrix austenitising process and the role of graphite in its carbonizing were presented in the paper [7].

Heating of the cast iron during austenitising practically takes places in range of 815 ÷ 950 ^{0}C. The effect of austenitising depends on the chemical composition of the matrix, the input structure of cast iron before quench hardening, emissions of graphite, temperature and time of warming, and on homogenity of elements in eutectic grains also and growth of grains. Investigations on the ADI cast iron are mainly concentrated on the ausferritie transformation [3, 8, 9]. It is very rational attitude because microstructure of the metal matrix has the main influence on formation of high strength, good plasticity and impact strength of the cast iron.

The investigation aimd at researching the influence of conditions of hardening with isothermal transformation, and in peculiarity the gradual austenitizing, that is of the nominal temperature t_γ and the precooling temperature $t_{\gamma'}$, of unalloyed ductile cast iron with ferrite matrix.

2. Material, program and methodology of investigations

The investigated ductile cast iron was smelted in a hot blow industrial acid cupola. The spheroidization of the cast iron was performed by the ML5 magnesium-alloy by means of the rod method in a reservoir of the cupola. The cast iron was cast to moist sand forms. The casts had the YII ingot shape according to (PN - EN 1563:2000). The cast ductile iron was classified to species EN - GJS-500-7 basing on the static tensile test. The cast iron was characterized by the ferrite - pearlite (10 % pearlite) structure of the matrix and the correct nodular graphite form (11,5 % graphite on surface, 112 precipitations/ mm^2 of the micro section).

The chemical composition and properties of the plain cast ductile iron are presented in the table 1.

Table 1.
Characteristic of cast ductile iron

	Chemical composition, % mas					
Component	C	Si	Mn	P	S	Mg
%, mas.	3,65	2,59	0,18	0,052	0,014	0,06

Mechanical properties			
R_m, MPa	A_5, %	HV10	KCG, J
507	12,1	156	106

Lower cuboidal parts of YII specimens were ferritizingly annealed according to the scheme presented in fig. 1.

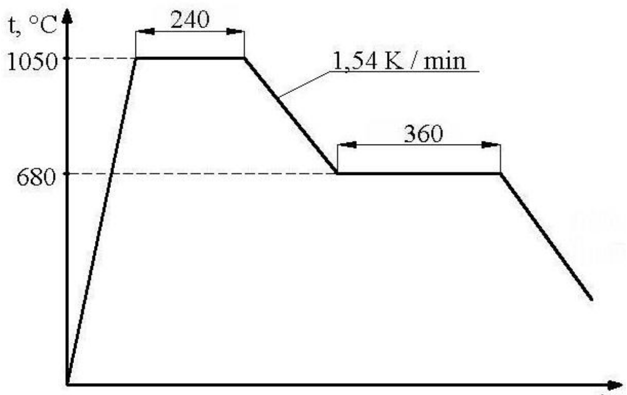

Fig. 1. The schema of dual-stage ferritizing annealing of the ductile cast iron

The rods (cross - section 10,5 x 10,5 mm, length 200 mm) cut out from a cuboidal part of a YII ingot, were hardened with the isothermal transformation in accordance with the schema presented in fig. 2.

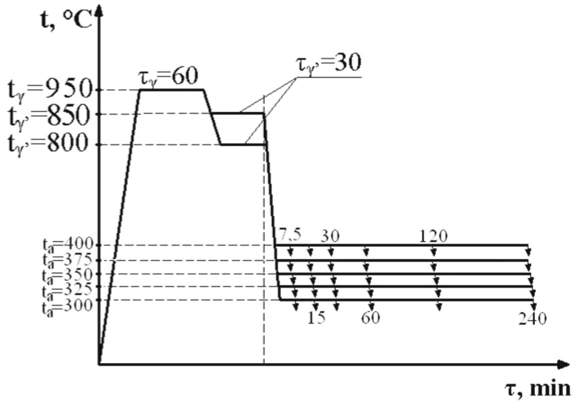

Fig. 2. The schema of hardening with the isothermal transformation of the ductile cast iron rods

The heat treated rods were cut into impact strength specimens with dimensions 10x10x55 mm. The measurement of hardness was executed on side surface of the impact samples according to the Rockwell's method the by weight 1471 N. The results of hardness of the HRC were exchanged by means of Vicker's table. Then the graphs were prepared and mathematical relationships were defined. For each measuring point, in three samples, there was defined the breaking work using the Charpy pendulum machine with striking energy 300 J. [17-19].

For the purpose of calculation the mathematical relationship was chosen second degree algebraical polynomial with double interactions. The statistical verification in reference to adequacy of function and significance her coefficients was based on analysis of variation (test *F*). On the select impact samples were performed the investigations of microstructure and breakthroughs by means of the light microscope and scanning electron microscope.

3. The results of investigations and their analysis

The results of investigations of mechanical properties as function of time of isothermal precooling are showed on the figures 3 ÷ 8.

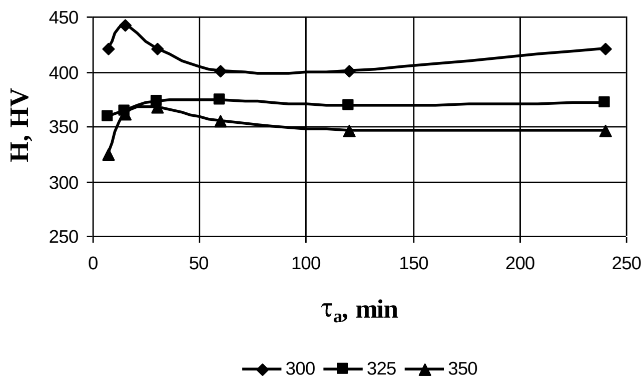

Fig. 3. The influence of isothermal transformation time τ_a on hardness of the hardened cast iron from temperature t_γ=950 ^{0}C and $t_{\gamma'}$=850 ^{0}C also in temperature t_a = 300, 325 and 350 ^{0}C

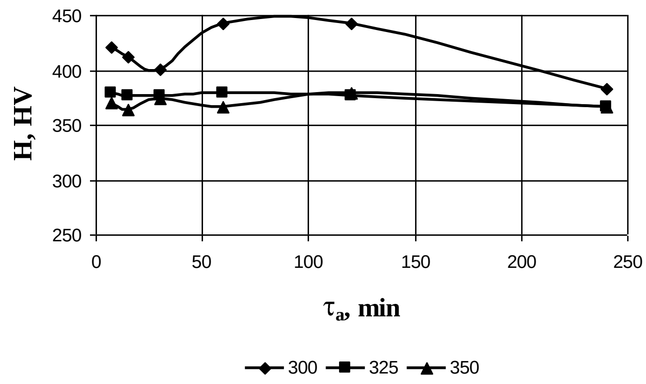

Fig. 4. The influence of isothermal transformation time τ_a on hardness of the hardened cast iron from temperature t_γ=950 ^{0}C and $t_{\gamma'}$=800 ^{0}C also in temperature t_a = 300, 325 and 350 ^{0}C

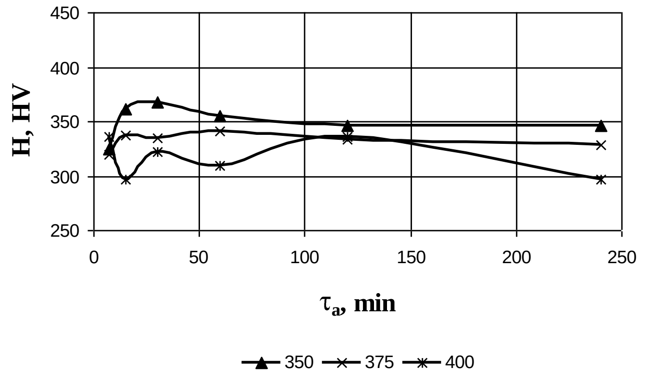

Fig. 5. The influence of isothermal transformation time τ_a on hardness of the hardened cast iron from temperature t_γ=950 ^{0}C and $t_{\gamma'}$=850 ^{0}C also in temperature t_a = 350, 375 and 400 ^{0}C

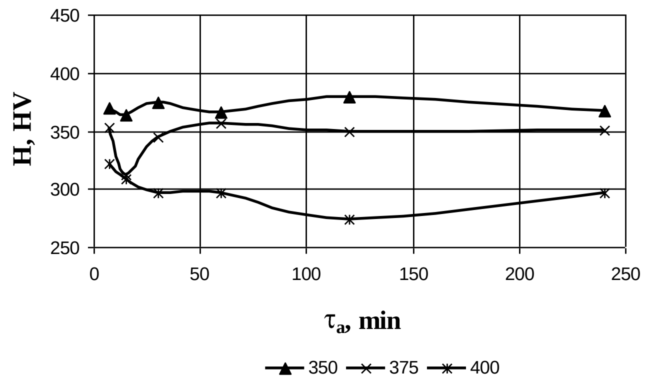

Fig. 6. The influence of isothermal transformation time τ_a on hardness of the hardened cast iron from temperature t_γ=950 ^{0}C and $t_{\gamma'}$=800 ^{0}C also in temperature t_a = 350, 375 and 400 ^{0}C

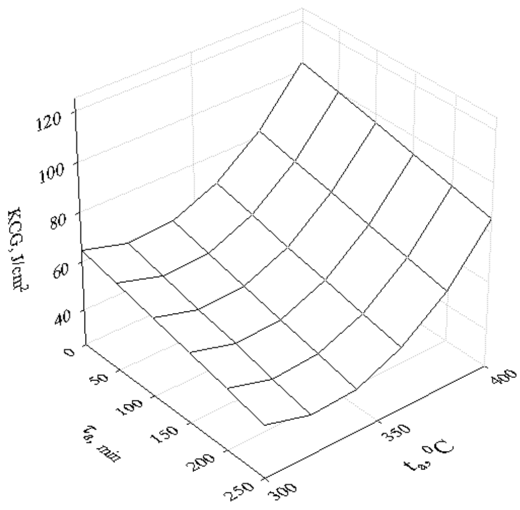

Fig. 7. The influence of temperature t_a and isothermal transformation time τ_a on impact strength of the hardened cast iron from temperature t_γ=950 ^{0}C and $t_{\gamma'}$=850 ^{0}C

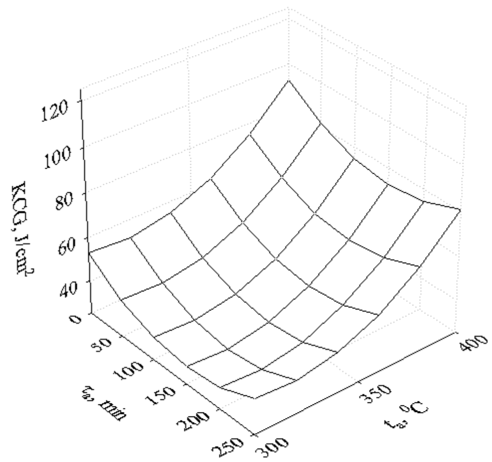

Fig. 8. The influence of temperature t_a and isothermal transformation time τ_a on impact strength of the hardened cast iron from temperature t_γ=950 ^{0}C and $t_{\gamma'}$=800 ^{0}C

Microstructure of the ductile cast iron of the hardened to temperature $t_{\gamma'}$ = 850 and 800 ^{0}C with isothermal transformation is showed on the figures 9 and 10.

The fracture of impact samples are showed on the figures 11 and 12.

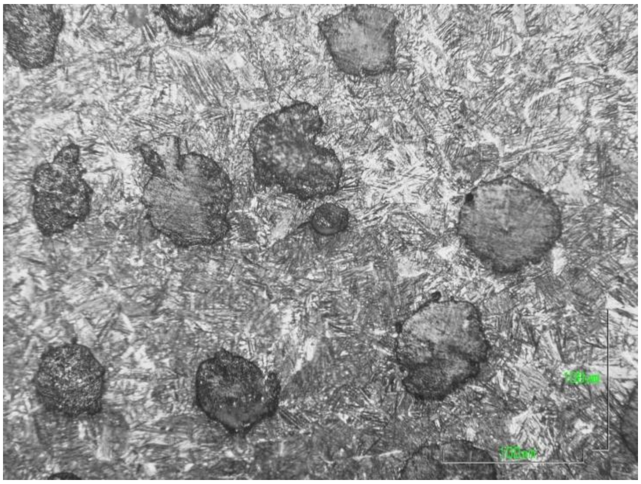

Fig. 9. Microstructure of the ductile cast iron of the hardened to temperature $t_{\gamma} = 950\ ^{0}C$ and $t_{\gamma'} = 850\ ^{0}C$ also in temperature $t_a = 350\ ^{0}C$ and time $\tau_a = 60$ min. Etched using 2 % solution of HNO_3

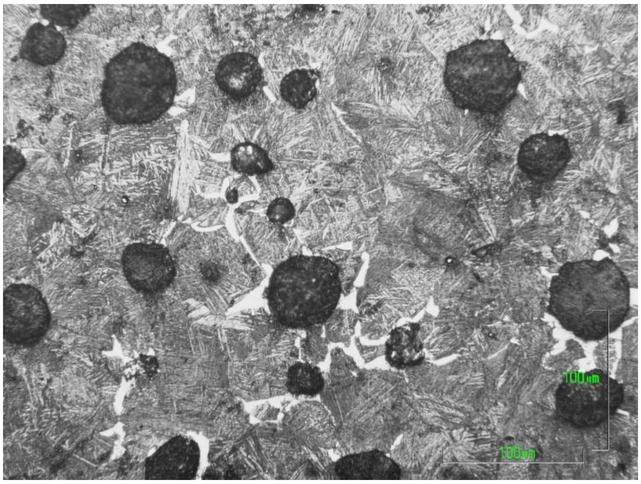

Fig. 10. Microstructure of the ductile cast iron of the hardened to temperature $t_{\gamma} = 950\ ^{0}C$ and $t_{\gamma'} = 800\ ^{0}C$ also in temperature $t_a = 325\ ^{0}C$ and time $\tau_a = 120$ min. Etched using 2 % solution of HNO_3

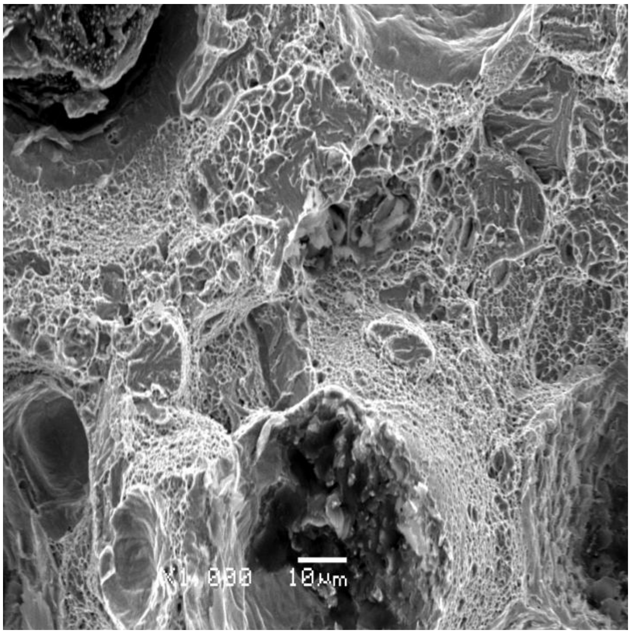

Fig. 11. The fracture of ductile cast iron of the hardened to temperature $t_{\gamma} = 950\ ^{0}C$ and $t_{\gamma'} = 850\ ^{0}C$ also in temperature $t_a = 375\ ^{0}C$ and time $\tau_a = 7,5$ min. SEM, magn. 1000x

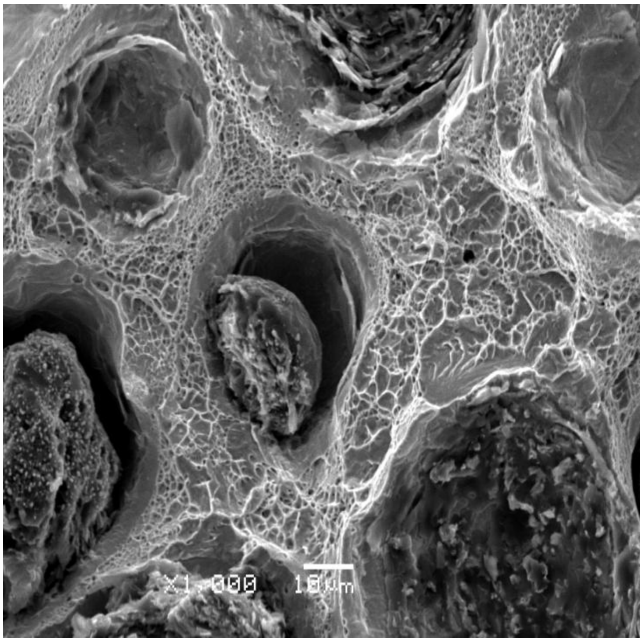

Fig. 12. The fracture of ductile cast iron of the hardened to temperature $t_{\gamma} = 950\ ^{0}C$ and $t_{\gamma'} = 800\ ^{0}C$ also in temperature $t_a = 325\ ^{0}C$ and time $\tau_a = 7,5$ min. SEM, magn. 1000x

In table 2 are presented the results of statistical analysis verification of hardness and impact strength properties as function of temperature and ausferritizing time.

Table. 2.
The statistical analyse of hardness and impact strength in function of temperature and time of the isothermal transformation

Fig. No.	t_γ - $t_{\gamma'}$ ^{0}C	t_a ^{0}C	Figure of equation	Unit	Correlation coefficient *r*
3.	950 - 850	350 - 300	$H = 3429{,}13 - 17{,}48 \cdot t_a + 0{,}025 \cdot t_a^2$	HV	0,925
4.	950 - 800	350 - 300	$H = 3699{,}15 - 19{,}46 \cdot t_a + 0{,}025 \cdot t_a^2 - 0{,}002 \cdot \tau_a^2 + 0{,}001 \cdot t_a \cdot \tau_a$	HV	0,922
5.	950 - 850	400 - 350	$H = 588{,}08 - 0{,}68 \cdot t_a$	HV	0,731
6.	950 - 800	400 - 350	$H = 604{,}27 - 0{,}0019 \cdot t_a^2$	HV	0,913
7.	950 - 850	400 - 300	$KCG = 931{,}11 - 5{,}34 \cdot t_a - 0{,}071 \cdot \tau_a + 0{,}0082 \cdot t_a \cdot \tau_a$	J/cm^2	0,871
8.	950 - 800	400 - 300	$KCG = 627{,}87 - 3{,}65 \cdot t_a - 0{,}26 \cdot \tau_a + 0{,}0058 \cdot t_a{}^2 + 0{,}001 \cdot \tau_a{}^2$	J/cm^2	0,887

Quench-hardened cast iron with the isothermal transformation it the range of lower ausferrite (t_a=350÷300 ^{0}C) had hardness, that was not influenced by $t_{\gamma'}$ temperature. Cast iron hardness after τ_a short periods of the transformation changed, but its elongation did not cause any significant changes. After time τ_a = 60 min chart segments had rectilinear character except t_a = 300 ^{0}C temperature. Cast iron in that range of temperatures had hardness 450÷350 HV.

Similar character of hardness changes was in quench-hardened cast iron with the isothermal transformation it the range of lower ausferrite (t_a=350÷300 ^{0}C), except $t_{\gamma'}$ = 800 ^{0}C and t_a = 400 ^{0}C temperatures. Matrix consisting of upper ausferrite, that cast iron had smaller hardness, i.e. in the range 370÷300 HV. That smaller hardness was influenced by kinetics of the ausferric transformation and connected with it bigger percentage content of austenite in cast iron matrix.

Content of austenite in ADI matrix is directly connected with its hardness. Austenite has a large content of carbon, larger than during austenitizing. It is called as high-carbon austenite, where can be up to 2 % of carbon. That is why the content of austenite and its beneficiation in carbon significantly influences on the level of ADI cast iron hardness, as well as plasticity.

Equation included in the table 2 that describe character of connection among hardness, impact strength and t_a ausferritic transformation temperature and its τ_a time showed on the base of *r*, correlation coefficient very strict dependence.

Using largest values of temperatures and hardness and their spread in the range of the transformation in t_a = 400÷300 ^{o}C temperature and τ_a = 15÷240 min transformation time, gradual quench-hardening was compared with the traditional one (tab. 3 and 4).

Table 3.
Comparison of largest values of hardness and their spread for not- and alloy quench hardening with the isothermal transformation of ductile cast iron

Entry	Temperature t_a, ^{o}C	Range time τ_a, min	Temperature t_γ i $t_{\gamma'}$, ^{o}C					
			950[1)]		950÷850		950÷800	
			Hardness, HV					
			max	Δ	max	Δ	max	Δ
1.	300	15÷240	436	21	392	18	402	28
2.	325	15÷240	-	-	375	10	380	13
3.	350	15÷240	341	21	369	23	380	14
4.	375	15÷240	-	-	352	34	357	36
5.	400	15÷240	285	22	287	30	287	38

1) results from the paper [5]

Table 4.
Comparison of largest values of impact strength and their spread for not- and alloy quench hardening with the isothermal transformation of ductile cast iron

Entry	Temperature t_a, ^{o}C	Range time τ_a, min	Temperature t_γ i $t_{\gamma'}$, ^{o}C					
			950[1)]		950÷850		950÷800	
			Impact strength KCG, J/cm^2					
			max	Δ	max	Δ	max	Δ
1.	300	15÷240	50,3	32,6	63,0	21,0	56,0	20,0
2.	325	15÷240	-	-	69,7	11,7	36,5	10,2
3.	350	15÷240	114,7	76,7	69,9	25,5	63,0	15,0
4.	375	15÷240	-	-	81,8	35,0	76,5	18,4
5.	400	15÷240	73,1	56,3	122,0	34,0	104,0	34,0

1) results from the paper [5]

Modified quench-hardening with the isothermal transformation of ferritic not-alloy ductile cast iron led to obtain ADI corresponding to a grade, mostly highly durable 1200/850/4 and in individual cases medium durable 1050/700/7 or 850/550/10. Evaluation was based on the standard ASTM A 897 M-90 and obtained hardness and impact strength test results.

4. Conclusions

On the base of performed tests and their results it can be stated that:

1. Gradual ausferritizing in heat treatment caused increase of ADI impact strength with maintenance of its hardness level except $t_a = 350\ ^0C$ temperature.
2. ADI cast iron after isothermal transformation in $t_a = 300$ and 400 ^0C temperature had hardness amounted adequately: 436, 392, 402 HV and 285, 287 and 287 HV (tab. 3).
3. Decrease of $t_{\gamma'}$ temperature by 50 ^0C caused insignificant increase of the largest value of hardness and noticeable decrease of ADI impact strength.
4. General evaluation of gradual austenitizing application should be also based on strength and plasticity tests of ADI.
5. Probably modification of ADI quench-hardening may lead to decrease of costs of heat treatment.

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