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The Influence of Lamellar Graphite Cast Iron Annealing on Hardness and Structure

J. Roučka [a,] *, J. Prochazka [a], V. Kana [a], V. Krutis [a], K. Nedelova [b]
[a] Brno University of Technology, Faculty of Mechanical Engineering
Technická 2896/2, 616 69 Brno, Czech Republic
[b] Slévárna Heunisch Brno, S.R.O.
Zaoralova 11, 628 00 Brno, Czech Republic
* Corresponding author. E-mail address: roucka@fme.vutbr.cz

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Abstract

An analysis has been carried out of the influence of annealing time at the preheating temperature of 650 °C on the change in hardness and alloy structure of lamellar graphite cast iron in the working as well as in the laboratory conditions. This preheat temperature is common during reclaiming welding of castings with complex shapes. The changes in unalloyed cast iron EN-GJL 200 to EN-GJL 300 according to ISO 1690 standard and cast iron with low amount of elements such as Sn, Cu, Cr, and Mo and their combinations were assessed. It was found that the cast iron of higher strength grades has better hardness and structural stability. Cast iron alloyed with chromium or its combinations has the highest stability. In unalloyed cast iron, a partial degradation of pearlite occurs; in alloyed cast iron the structural changes are not conclusive.

Keywords: Welding cast iron, Annealing, Cast iron hardness, Structure stability

1. Introduction

Many cast iron castings may have local defects, disruptions or some other damage that can be fixed by welding up. In foundry practice, oxy-fuel welding or arc welding are commonly used processes. The welding area must be rid of any impurities before welding, cleaned and treated so as to make a good and solid connection.

Fusion welding of graphite cast iron is complicated due to the metallurgical processes that occur during metal melting of the cast, interaction between the basic metal with the additional metal and consequently during solidifying and cooling of the welded joint. At welding temperatures, the graphite is dissolved in the metal matrix and at fast cooling during solidifying a ledeburite structure may occur locally. During the subsequent fast cooling of the metal below transformation temperatures A1, martensite may occur. Ledeburite and martensite are exceptionally hard and brittle structural phases whose presence in the casting worsens machinability or even makes it impossible. At the same time, the brittleness of the casting rises in the welding joint area. Therefore, it is imperative to slow down the heat removal from the welded joint by local or full-body preheating of the casting. We can also partially prevent the occurrence of brittle phases by choosing an appropriate chemical composition of the additive material.

The casting preheating temperatures are chosen according to the type of cast iron, its chemical composition, the casing wall thickness, its complexity and the welding process in the range from 250 to 700 °C; in more complex castings with bigger wall thickness from 550 to 700 °C. These preheating temperatures correspond approximately to the highest temperature of the annealing temperature range to reduce the internal stress. During welding the internal stress is reduced, which prevents the possibility of cracks and casting deformations. At the same time, however, the preheating temperatures are close to the temperatures for low temperature ferrite annealing that range from 700 to 760 °C for unalloyed cast iron, and for ferritization the delay of 1 to 3 hrs is long enough – Fig 1.

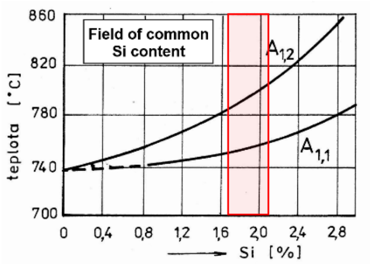

Fig. 1. Transformation temperatures for common Si contents in GJL cast iron [1]

Long-term heating at temperatures that are reaching eutectoid transformation values may cause a change in the structure particularly the creation of globular pearlite and its partial breaking into ferrite – this transformation is accompanied by a decrease in hardness of the casting material. After welding witness a significant drop in hardness, in some cases even below the required standard, is often detected.

The aim of the research is an analysis of the influence of the preheating temperature delay on the change in mechanical properties of unalloyed and low-alloy cast iron with lamellar graphite.

2. The influence of preheating on cast iron properties

2.1. Types of cast iron observed, and conditions for melting and casting repair

The analysis of the influence of the preheating time on the change in casting hardness was carried out in the foundry workshop, which works with cast iron with lamellar graphite. This foundry makes mainly medium size products with complex shapes that are used for agricultural machinery, trucks and other heavy machines with weight ranging from 30 to 400 kg. The castings are mostly of complex shapes with many cores, internal walls and with different wall thicknesses ranging from 15 to 45 mm. The moulds are made using high pressure moulding from bentonite mixtures, cores from CO_2 or Cold-box mixtures.

Unalloyed and low-alloy cast iron of GJL according the ISO 1690 standard is cast in the foundry. Unalloyed cast iron GJL 200 is used for castings with low mechanical stress, cast iron GJL 250 that is cast either as unalloyed or alloyed with tin and for castings with high mechanical stress either unalloyed GJL 300, or alloyed with Sn, Cu, Cr, Mo or their combinations to obtain the required properties are used. The choice of the alloying elements and their content is linked to particular casting items.

The basic cast iron is melted in a cupola furnace in combination with a channel-type induction furnace. Metal is poured from the channel-type furnace into a transport ladle, which serves for casting as well, where it is alloyed and inoculated. A sample for thermal analysis, chemical analysis and a test bar for mechanical tests is taken from each 2200 kg ladle. The thermal analysis results are used operatively to make the ladle available for casting. Thermal analysis itself is used to find out the content of carbon, silicon, and carbon equivalent.

The standard mechanical tests include a tensile strength test and the measurement of hardness by Brinell method carried out on samples from separately cast ø 30 mm test bars. Metallographic analysis is carried out in irregular intervals.

Casting hardness is tested after the finishing process according to the customer's needs. The customer's requirements for hardness usually concern reaching the minimal hardness in specific parts of the casting. Since the castings are large, complex and inaccessible, Shore scleroscope is used to measure hardness.

EutecTrode 2-26 electrodes by Castolin Eutectic for fusion welding repairs are used. This electrode has a recommended preheating temperature of the castings in the range of 550 – 700°C. The preheating temperature of 650°C is used unanimously in the foundry. The preheating is done in the continuous heating gas furnace. The castings are slowly cooled in the furnace cooling branch after welding up. The thermal regime and time delay of the castings in the furnace depend on the working regime at the welder's workplace and these are not stable for individual castings during a working shift. When the repair is finished, the hardness as per Shore at certain places is measured. The castings that fail the hardness test are discarded or heat-treated again.

The aim of the present research is to verify the influence of the preheating time of the castings on the change in the structure and mechanical properties that are represented by hardness on cast iron of different chemical composition, cast in the stated foundry workshop.

2.2. Cast iron assessed

The research was carried out on unalloyed and low-alloy cast iron commonly cast in the given foundry workshop corresponding to the quality standard of GJL 200, GJL 250 and GJL 300. Alloying is made up to the contents of 0.3 %Cr, 0.65 %Cu, 0.10 %Sn and 0.35 %Mo – tab. 1. These materials can be labelled as:

– GJL 200
– GJL 250
– GJL 250 Sn 0,1
– GJL 300
– GJL 300 Sn 0.1
– GJL 300 Cu 0.3
– GJL 300 Cr 0.3
– GJL 300 Cu 0.5 Cr 0.3
– GJL 300 Cu 0.6 Mo 0.3

2.3. Assessing the change in hardness of the castings during reclaiming welding in foundry conditions

We selected three same castings of every cast iron type from the range of products. (Since the chemical composition often corresponds to a particular production item, for every cast iron type we compare castings that are different in shape.) Hardness as per Brinell and Shore was measured in every casting in two areas with different wall sizes. Consequently, a common operating heat cycle of preheating and cooling was carried out. Hardness was measured again in the same spots after cooling and a metallographic analysis was conducted on some samples. Hardness was measured three times in the same spots, therefore, 9 measurements as per Brinell and Shore altogether were made on every casting type from the same alloy.

Table 1.
Chemical composition, hardness and strength of test bars in the cast state

Alloy	Cast Nr.	%C	%Si	%Mn	%P	%S	%Cr	%Cu	%Mo	%Sn	CE	R_m [MPa]	HB
GJL 200	1	3,45	2,19	0,69	0,059	0,060	0,07	0,08			4,20	240	178
	2	3,46	2,00	0,62	0,069	0,085	0,07	0,11			4,15	252	179
	18	3,41	2,14	0,64	0,091	0,066	0,09	0,09			4,15	241	192
	19	3,48	2,04	0,59	0,064	0,075	0,08	0,10			4,18	242	178
GJL 250	3	3,41	1,91	0,65	0,053	0,079	0,08	0,11			4,06	270	194
	4	3,38	1,93	0,67	0,052	0,072	0,07	0,11			4,04	264	194
	20	3,39	1,88	0,73	0,071	0,071	0,08	0,09			4,04	271	199
	21	3,39	1,85	0,64	0,058	0,085	0,08	0,08			4,03	265	193
GJL 250 Sn	5	3,40	1,81	0,62	0,047	0,072	0,07	0,09		0,09	4,02	287	206
	6	3,44	1,92	0,72	0,069	0,068	0,07	0,12		0,10	4,10	280	201
	22	3,37	1,81	0,65	0,084	0,080	0,08	0,08		0,09	4,00	283	203
	23	3,38	1,92	0,75	0,078	0,061	0,07	0,08		0,08	4,05	274	204
GJL 300	7	3,30	1,91	0,86	0,076	0,081	0,18	0,28			3,96	303	212
	8	3,37	1,71	0,62	0,083	0,083	0,11	0,10			3,97	303	207
	24	3,28	1,58	0,73	0,079	0,073	0,07	0,11			3,83	306	206
	25	3,31	1,69	0,74	0,059	0,092	0,07	0,07			3,89	303	209
GJL 300 Sn	17	3,34	1,82	0,83	0,075	0,091	0,08	0,12		0,10	3,97	290	211
	34	3,31	1,70	0,76	0,049	0,066	0,08	0,11		0,09	3,89	306	215
GJL 300 Cu	9	3,27	1,72	0,82	0,097	0,080	0,13	0,33			3,88	322	216
	10	3,27	1,86	0,79	0,066	0,075	0,06	0,33			3,91	318	212
	26	3,27	1,65	0,80	0,070	0,061	0,07	0,31			3,84	322	214
	27	3,27	1,75	0,76	0,053	0,075	0,09	0,33			3,87	315	213
GJL 300 Cr	11	3,33	1,82	0,90	0,057	0,061	0,35	0,90			3,96	321	216
	12	3,30	1,75	0,78	0,060	0,063	0,30	0,10			3,90	318	214
	28	3,28	1,61	0,77	0,076	0,076	0,30	0,09			3,84	322	219
	29	3,26	1,74	0,79	0,074	0,067	0,29	0,11			3,86	318	215
GJL300 CuCr	13	3,30	1,70	0,84	0,072	0,087	0,31	0,47			3,89	318	225
	14	3,27	1,78	0,79	0,063	0,066	0,30	0,50			3,88	322	227
	30	3,26	1,73	0,76	0,090	0,068	0,35	0,52			3,87	322	216
	31	3,28	1,68	0,77	0,063	0,071	0,30	0,51			3,86	331	228
GJL 300 CuMo	15	3,33	1,74	0,74	0,061	0,067	0,09	0,60	0,35		3,93	344	240
	16	3,28	1,85	0,81	0,077	0,062	0,09	0,60	0,36		3,92	360	232
	32	3,29	1,72	0,76	0,058	0,060	0,08	0,60	0,37		3,88	347	233
	33	3,33	1,70	0,80	0,072	0,067	0,09	0,66	0,38		3,92	331	237

Note: CE = C + 1/3(Si + P)
Chemical elements content in wt.%

The continuous annealing furnace used does not allow precise measurement of the heat cycle. The heat cycle period was not the same for all the castings as it always corresponded to a regular working regime in the foundry shop.

After conducting the whole heat cycle, both measurement methods showed a drop in hardness in all the types of cast iron. The average drop in hardness in certain places ranges approximately from 0 to15 HB or 15 to 45 Sh - Tab 2.

Table 2.
The change in casting hardness after the heat cycle in foundry conditions

Cast iron	Point 1		Point 2	
	Wall thickness [mm]	Δ HB	Wall thickness [mm]	Δ HB
GJL 200	28	5	25	9
GJL 250	31	16	26	8
GJL 300	15	16	35	6
GJL 300 Cu	42	-1	27	4
GJL 300 Cr	17	9	36	2
GJL 300CuCr	43	12	12	3
GJL 300CuMo	15	16	36	0

* The values of the hardness change are always the average values from 9 measurements for every cast iron type and a measured place. The positive values Δ HB show the hardness drop after the heat cycle.

Hardness values have a significant range of scatter and no correlation between the types of cast iron or correlation that would depend on the wall thickness was found. We can merely state that during the common welding cycle process there is a hardness drop in almost all the cast iron types. No evident changes can be found on the microstructures before and after the heat cycle. Because of the ambiguous conditions of the heat cycle, the tests were subsequently carried out in the laboratory conditions.

2.4. The influence of annealing on the structure and hardness of the cast iron during heat treatment in the laboratory conditions

The influence of the long-time annealing on the cast iron was examined in the laboratory conditions at the BUT Department of Foundry Engineering. The purpose of this measurement was to carry out the tests with higher accuracy and in the uniform terms of the heat treatment for all cast iron assessed, which cannot be obtained in the working conditions.

Tensile test bars (ø30 mm and 300 mm in length), which are commonly cast during casting manufacture, always one bar from each ladle of a particular type of cast iron, were used as samples for every type of cast iron to assess the influence of the annealing time on the change in hardness. From every cast iron type we assess four bars from four different ladles. The measurement set comprised of 34 samples (for the GJL 300Sn cast iron only two bars). Every bar was cut into five samples of 30 mm in length. These samples were used for subsequent heat treatment, for the hardness tests and for the metallographic analysis.

Fig 2 shows the tensile strength (left scale) and hardness values (right scale) on the test bars in the as-cast state. (as an average value of all the samples for a particular cast iron). It is obvious that alloying the cast iron increased the strength and hardness in all cases and the influence of the combination of the Cu Cr or Cu Mo alloying elements is more significant than each of these elements individually.

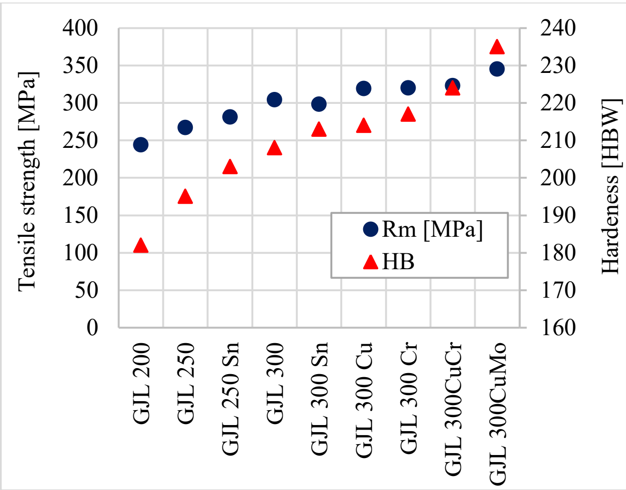

Fig. 2. The dependence of R_m and HB in the as-cast state

The individual parts of the test bars, were annealed in the laboratory furnace at the temperature of 650 ^{o}C. Every 1.5 hrs one part from each type of the cast iron was taken out of the furnace and cooled in open air. The last pieces were taken out of the furnace after annealing for 6 hrs. The Brinell hardness HBW 10/3000 was measured on the grinded front surfaces.

Graphs on Fig. 3 show dependences of the hardness change on the annealing time for each type of cast iron. Every point is the average of three hardness measurements and every curve in the graph assesses cast iron from a different ladle (not quite uniform chemistry – see Tab 1). The graphs show that the scatter of the values measured between the properties of the individual samples of the same sort of cast iron is rather small, and therefore the working process stability is quite high. Fig 4 shows the overall hardness on annealing time dependence. (Sample numbers in the graphs correspond to casting Nr. in the table 1.)

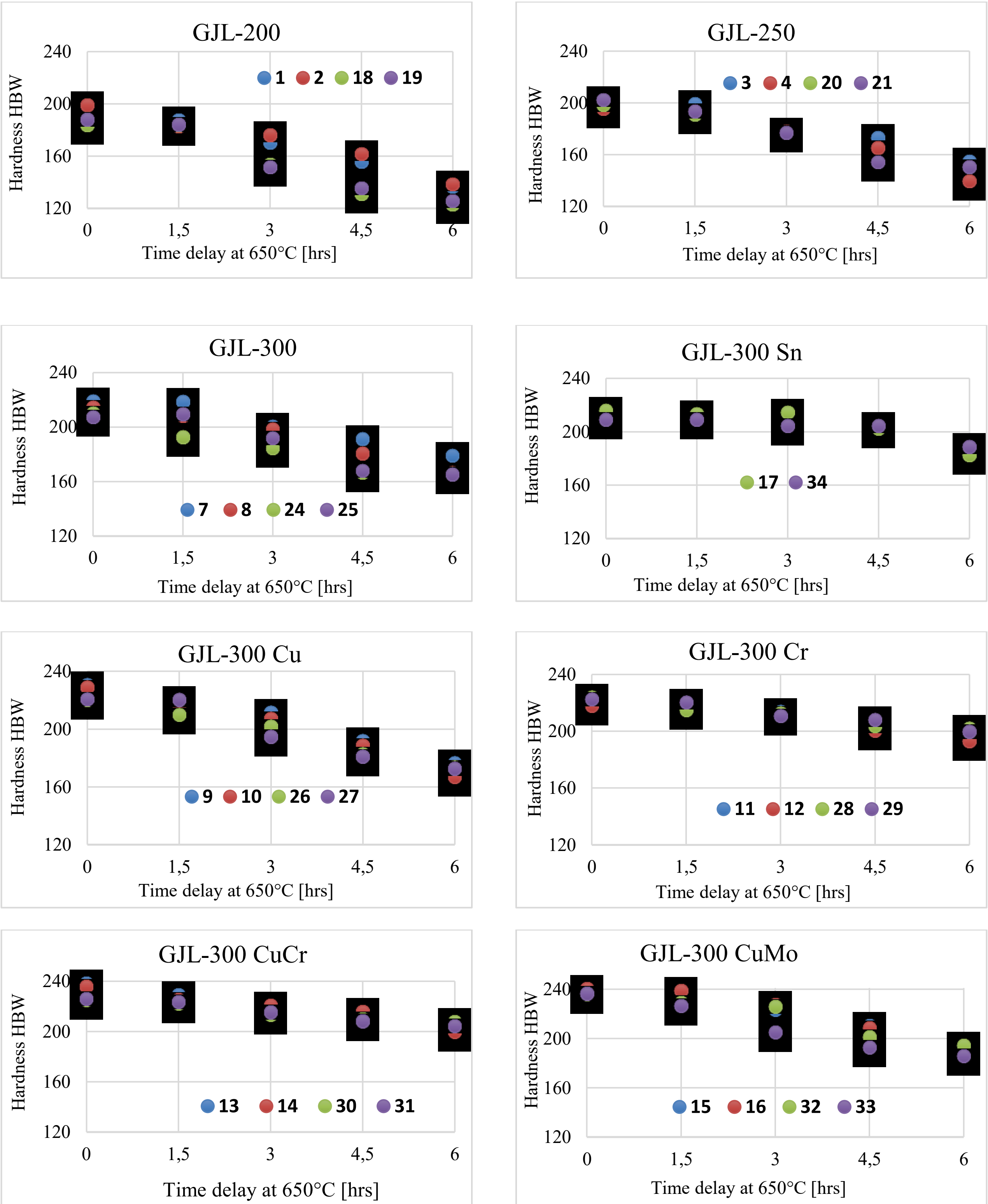

Fig. 3. Dependence of hardness on annealing time (sign of curves correspond to cast Nr. in table 1)

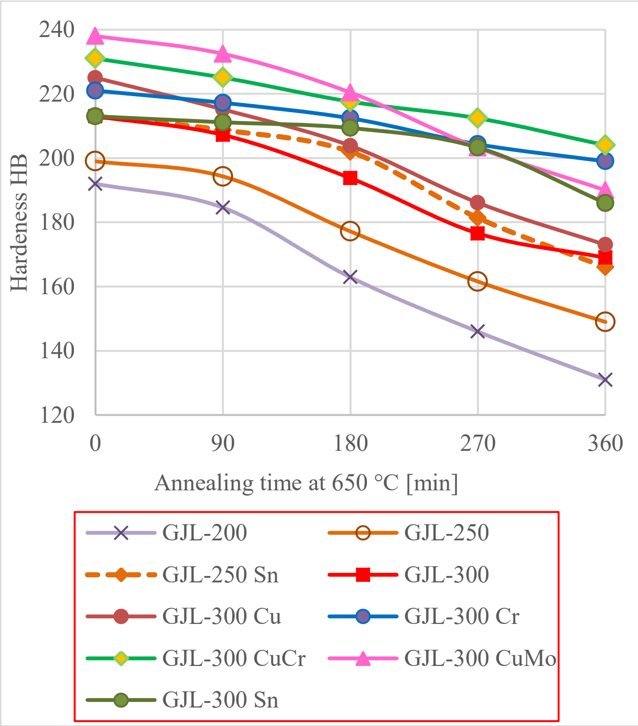

Fig. 4. Cast iron hardness change during annealing

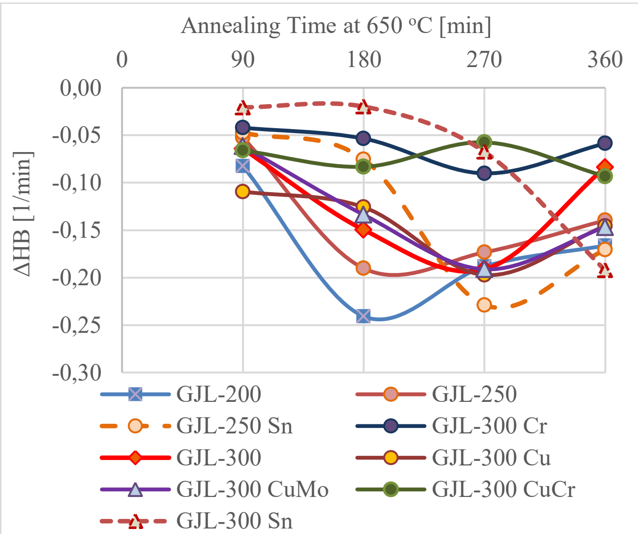

Fig. 5. Hardness drop rate during annealing at 650 °C

The rate of hardness drop in the assessed cast iron changes during annealing. After a small hardness drop during heating the sample to the annealing temperature there is a period of a significant hardness drop. The hardness drop gradually slows down with the annealing time. The hardness change is connected to the initial pearlitic structure stability as the subsequent metallographic analysis proved. Fig. 5 shows that in unalloyed cast iron, more stable types are those with a higher strength grade. Hardness stabilizes especially by alloying with chromium or its combinations with other alloying elements. Alloying with copper does not ensure structural stability.

The hardness decrease ΔHB by 90, 180, 270 and 360 min annealing time and average decrease per hour is course of 6 hrs. annealing is stated in Tab. 3 and represented in fig.6.

Table 3.
Hardness decrease ΔHB in course of annealing at 650 °C in the given period of annealing time (in min.)

	ΔHB_{90-0}	ΔHB_{180-0}	ΔHB_{270-0}	ΔHB_{360-0}	avg ΔHB/hr in course of 6 hrs annealing 650 °C
GJL 200	7	29	46	61	10,1
GJL 250	5	22	37	50	8,7
GJL 250 Sn	4	11	31	47	8,0
GJL 300	6	19	34	44	7,5
GJL 300 Sn	2	4	10	27	4,5
GJL 300 Cu	10	21	39	52	8,7
GJL 300 CuMo	6	18	35	48	8,1
GJL CuCr	6	13	19	27	4,7
GJL 300 Cr	4	9	17	22	3,7

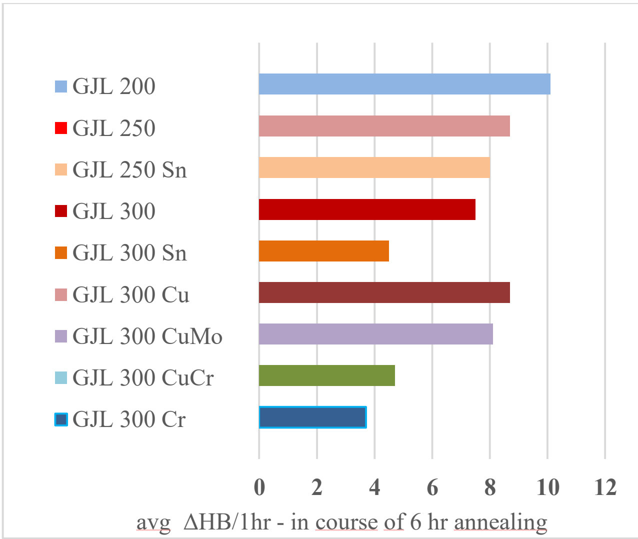

Fig. 6. Average hardness decrease ΔHB/hr

3. The influence of annealing on the structure

Metallographic analysis was conducted on the test bar samples for hardness tests in the state before heat treatment and after annealing for 6 hrs at the temperature of 650°C. GJL 250 and particularly GJL 200 cast iron showed a significant transformation of pearlite and increase of ferrite proportion from the initial 80-90 % to 40-70 % during annealing – fig. 7a-b. The pearlite also partially transformed into globular form – Fig. 8a-8l. Perlite-ferrite transformation appears after 6 hrs. annealing in non-alloyed iron sorts and iron alloyed by Sn – fig 8d. Very massive perlite-ferrite transformation arise by Cu alloyed iron – fig 8f, accompanied by hardness decrease. Copper addition doesn´t promote perlite stability nor in combination with molybdenium. Alloying by chromium separately or combined with copper supports perlite stability very considerably. Molybdenum influence is similar to chromium.

No changes either of graphite form or size appear in course of annealing.


Fig. 7a: GJL 200 - cast state


Fig. 7b: GJL200-anneal 6 hrs


Fig. 8a: GJL 300 – as cast

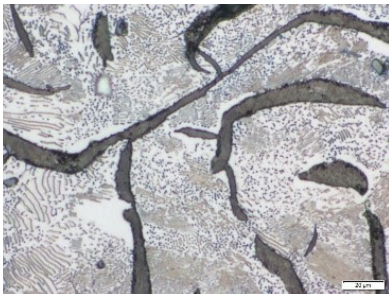
Fig. 8b: GJL 300 – 6 hrs

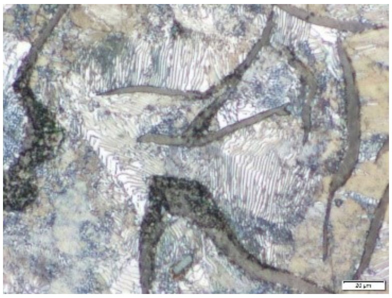
Fig. 8c: GJL 300 Sn–as cast

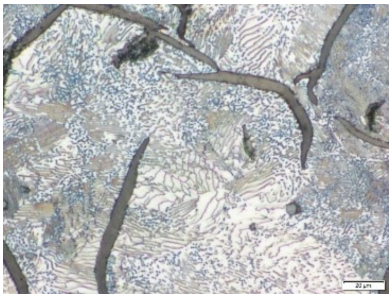
Fig. 8d: GJL 300 Sn –6 hrs

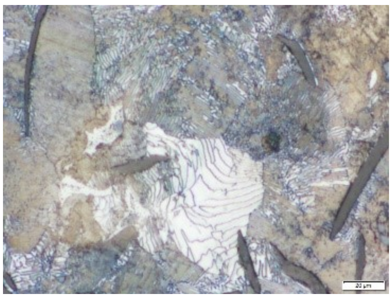
Fig. 8e: GJL 300 Cu – as cast

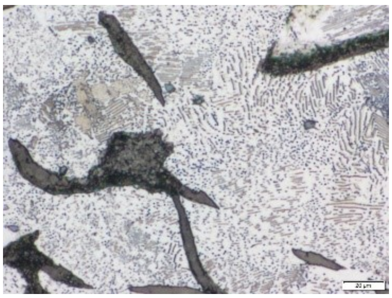
Fig. 8f: GJL 300 Cu – 6 hrs

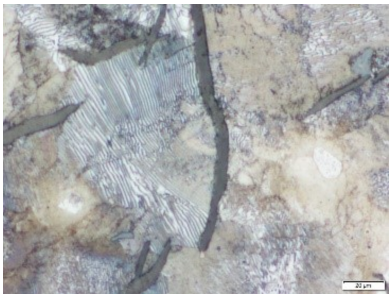

Fig. 8g: GJL 300 Cr – as cast

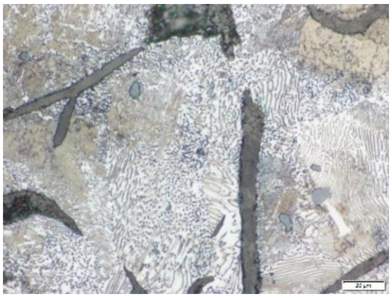

Fig. 8h: GJL 300 Cr -6 hrs

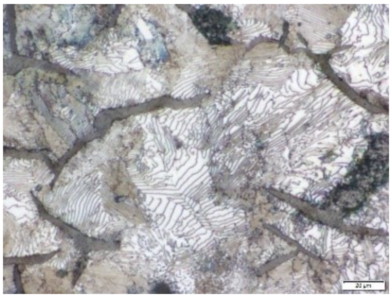

Fig. 8i: GJL 300 CuCr –as cast

Fig. 8j: GJL 300 CuCr - 6 hrs

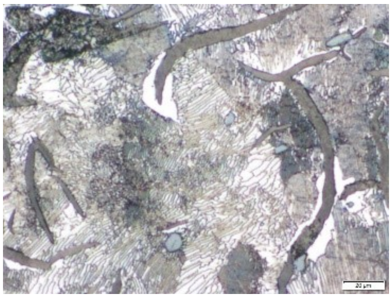

Fig. 8k: GJL 300 CuMo– as cast

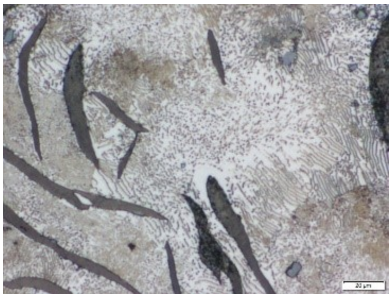

Fig. 8l: GJL 300 CuMo – 6 hrs

4. Conclusions

Hardness change and structure stability was assessed during annealing at temperature of 650°C in the interval of 1.5 to 6 hrs on unalloyed and low-alloyed lamellar graphite iron with the content of Sn, Cu, Cr and Mo in different combinations. We have found that during annealing a partial creation of globular perlite and ferritic structure occurs. These changes lead to a drop in hardness. These changes occur after a short annealing time of 1 to 2 hours intensively and they gradually slow down. The degradation process is slower in cast iron of higher tensile grades and cast iron with the Sn content. Alloying only with Cu does not ensure improving the structural stability and properties. Alloying with Cr and combinations of Cr, Mo and Cu leads considerable to structural stability and slows hardness degradation.

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