Quality and properties of the cast iron produced on the steel scrap base

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ABSTRACT

Purpose: The goal of the article is to show the issue of the cast iron melting on the steel scrap base only (with no pig iron in charge). The particular interest was focused on the charging material chemical composition influence on the particular elements content in produced cast iron and its quality, too.

Design/methodology/approach: The grey cast iron melting on the steel scrap base and recarburizers (anthracite, natural and synthetic graphite, petroleum coke) was conducted to achieve the goals of the experiments. The chemical composition, mechanical properties and microstructure was tested for each melt. Melting was conducted in inductive furnace of 20kg capacity.

Findings: The experiments drawn to the conclusions that cast iron melted on the steel scrap base contains less impurities (sulfur and phosphorus) than this melted on the pig iron base. During the results further analysis the relationship between carburizer grade and both mechanical properties and microstructure of the produced cast iron was proved (microstructure heredity).

Research limitations/implications: To finally prove the hypothesis regarding the microstructure heredity given in the article, further researches should be carried out with the anthracite use as a carburizer.

Practical implications: The results achieved suggest that when anthracite is used as a carburizer it is possible to increase mechanical properties with no necessity of changing other process parameters. Regarding the fact that the anthracite is relatively cheap carburizer it may cause in consequence less expensive production along with the cast iron quality parameters increase.

Originality/value: The issue of the materials microstructure heredity is not widely described in the literature and the experiments results presented in the article allow to create the hypothesis that this phenomenon is present in the metal alloys.

Keywords: Cast iron; Recarburization; Heredity of structure; Mechanical properties; Cast iron quality

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PROPERTIES

1. Introduction

When grey cast iron or even ductile iron is melted the charging materials composition can be changed with limited or even with no pig iron quota in it. This approach reduces melting cost but on the other hand forces the carbon addition into alloy necessity. Recarburization process can be carried out as: carburizer addition into solid charge, throwing it onto liquid metal surface or pneumatic carburizer injection in carrier gas jet. The particular method choice depends on the melting furnace type (cupola,

inductive furnace or electric arc furnace) and carbon deficit value. The important issue is the proper carburizer selection, too. The various carburizers are used in foundry engineering. These are: anthracite, natural and synthetic graphite and petroleum coke whilst in cupola process the foundry coke is kind of indirect carburizer. These materials are characterized by different carbon content, ash, sulfur and volatile parts. From the chemical composition point of view good carburizers should have the highest possible carbon content and the lowest possible sulfur, phosphorus and volatile parts content. The carburizers differ one from each other in microstructure, too. Natural graphite and anthracite have smooth and compact surface whilst synthetic graphite and petroleum coke have porous 'rotational-leaf-like' texture. In every carburizer there are visible thin, parallel graphite flakes or leaves. Such flakes are visible in anthracite but under very large magnifications (approx. x70000). The analyzed materials differ one from each other in crystallographic degree of order. Microstructure elementary units of the natural and synthetic graphite are much bigger than those of anthracite and petroleum coke. When higher carbon deficit in alloy must be compensated (something around 3%C) when significant carburizer amount is necessary to use, these features can be forwarded to the cast iron melted and in some extent can decide of its properties and microstructure.

The important issue in recarburization process is the highest possible yield of carbon assimilation from the carburizer (recarburization efficiency) [1,2]. This parameter is changed with such factors as: mutual movement of molten metal and carburizer, contact surface development between reacting phases, proper temperature of the recarburization process. The carburizer selection is essential, too, because their thermal-physical properties (thermal conductivity coefficient λ, specific heat capacity c_p) vary for each carburizer. During the initial dissolution stage the heating of the carburizer particles occurs. Specific heat capacity of the synthetic graphite and petroleum coke is slightly higher than for the anthracite. However, thermal conductivity coefficient of the carbon-based and graphite-based carburizers differ very much. Graphite-based materials conduct the heat well, occupying in terms of thermal conductivity place between aluminum and carbon steel. On the other hand coal-based materials possess thermal conductivity coefficient up to 100 times less than for graphite-based materials. This results that some kinds of carburizers should be used when introduced onto liquid metal surface and others when charged together with solid charging materials [3,4].

The thermodynamic state of the liquid iron and its susceptibility to hard spots can change under the same chemical composition of metal and solidification kinetics regarding to the charging materials used. The opinions exist which assign a huge role to graphite content and form in charging materials and trace elements content, including gases [5,6,7]. When charging material contains graphite in form of thick flakes the final cast iron have a tendency to crystallize with similar form of graphite in solidified castings. When charging material contains small graphite precipitates or is free of them completely (white pig iron, white iron scrap etc.) the situation leads to similar microstructure in the castings creation. It comes from stability of the exogenic graphite particles which serve as crystallization nuclei during the crystallization process [8,9,10,11].

2. Experimental procedure and results

During the researches the melts of the grey cast iron on the steel scrap base only and carburizers (natural and synthetic graphite, anthracite, petroleum coke, cupola coke and charcoal) were carried out [12]. Some melts were made on the pig iron base for comparison purpose. The carburizers were introduced into furnace with solid charge in previously calculated and weighted portions. The melting process was carried out inside high frequency inductive crucible furnace of 20 kg capacity. The steel scrap mass was between 10 and 15 kg. The carburizers were added in various mass portions what comes from intention to achieve similar final carbon content in cast iron. In each melting process the silicon content was increased by FeSi75 addition onto liquid metal surface after the charge was melted down.

For recarburization purpose during cast iron melting process were used: natural graphite (GN), calcined anthracite (A), synthetic graphite (GS), calcined petroleum coke (KN), cupola coke (KO) and charcoal (WD). The chemical composition of the carburizers used was presented in Table 1. In case of several materials from the same group (A, GS i KN) minimum and maximum values were shown. The anthracite and petroleum coke used in foundry engineering as carburizers are calcined. The calcination process consists of heat treatment of the raw materials without air access in temperature 1300-1800°C. The materials chosen for the tests are imported carburizers commonly used in domestic foundries.

Table 1.
Chemical composition of the carburizers used

Carburizer type		Chemical composition					
		C %	S %	Vol. parts %	Ash %	N %	H %
GN		85.0	0.08	3.0	11.0	0.10	0.41
A	min	92.0	0.1	0.7	3.5	0.36	0.27
	max	96.0	0.2	1.0	8.0	0.46	0.53
GS	min	99.0	0.01	0.1	0.2	0	0.28
	max	99.7	0.04	0.3	0.9	0.01	0.32
KN	min	98.0	0.03	0.20	0.26	0.68	0.39
	max	99.7	0.80	1.0	0.9	1.98	0.46
KO		88	0.80	1.4	10.5	-	-
WD		83	0.0	13.3	2.1	-	-

The chemical composition of the steel scrap used during cast iron melting was presented in Table 2.

Table 2.
Chemical composition of the steel scrap used

C %	Si %	Mn %	P %	S %	Cr %	Ni %	Cu %
0.207	0.18	0.60	0.026	0.015	0.086	0.119	0.277

The final cast iron chemical compositions were presented in Table 3. The numbers at carburizer mark e.g. A1, A2 mean that the materials were supplied by different suppliers. The particular elements content was presented in %, whilst the nitrogen content in ppm. The melts marked with S were made on the pig iron base. The melts S-26S and S-10G were carried out in laboratory conditions whilst the melts S-14T and S-15T in industrial conditions in inductive furnace.

Table 3.
Chemical composition of the cast iron melted during the experiments

Melt No.	C %	Si %	Mn %	P %	S %	Cr %	Ni %	Cu %	Al %	N ppm
A1-4G	2.84	2.14	0.49	0.035	0.031	0.066	0.093	0.293	0.013	120
A1-18S	3.55	2.12	0.16	0.024	0.0195	0.191	0.106	0.317	0.000	76
A2-9T	3.55	1.90	0.56	0.025	0.020	0.094	0.094	0.294	0.008	
A2-7N	3.43	2.16	0.60	0.028	0.027	0.095	0.090	0.270	0.008	83
A3-8T	3.20	1.80	0.40	0.030	0.020	0.176	0.092	0.300	0.001	
GN-9S	3.53	2.17	0.23	0.023	0.030	0.114	0.103	0.45	0.000	103
GN-8G	3.21	2.16	0.38	0.026	0.028	0.127	0.092	0.278	0.000	66
GS1-2G	3.17	2.13	0.44	0.018	0.023	0.079	0.095	0.285	0.013	91
GS1-21S	3.51	2.09	0.23	0.021	0.017	0.364	0.118	0.303	0.000	78
GS2-3T	3.29	1.90	0.43	0.023	0.019	0.143	0.083	0.472	0.003	63
GS2-1T	3.26	2.24	0.40	0.033	0.017	0.165	0.099	0.618	0.033	
GS3-5T	3.30	1.96	0.46	0.033	0.024	0.132	0.093	0.284	0.008	
GS4-6N	3.45	1.84	0.56	0.036	0.035	0.104	0.092	0.311	0.002	66
KN1-22S	3.46	2.13	0.48	0.026	0.024	0.196	0.104	0.317	0.010	160
KN1-7G	3.25	2.12	0.49	0.023	0.038	0.080	0.089	0.279	0.000	166
KN2-27S	3.25	2.12	0.41	0.026	0.029	0.075	0.094	0.271	0.000	128
KN2-5G	3.16	2.14	0.48	0.022	0.032	0.068	0.087	0.291	0.013	145
KN3-4T	3.32	1.90	0.43	0.024	0.027	0.077	0.088	0.275	0.003	63
KN3-2T	3.34	2.12	0.37	0.029	0.028	0.081	0.104	0.306	0.012	
KN4-6T	3.34	1.96	0.48	0.043	0.047	0.079	0.092	0.299	0.005	106
KN5-4N	3.19	2.10	0.49	0.022	0.020	0.120	0.073	0.273	0.005	83
WD-12T	3.17	1.95	0.57	0.025	0.015	0.072	0.091	0.289	0.001	54
KO-13T	3.00	2.15	0.56	0.052	0.033	0.147	0.084	0.269	0.002	
KO-8N	3.55	2.16	0.56	0.033	0.039	0.086	0.090	0.507	0.005	127
S-26S	3.3	1.99	0.38	0.052	0.021	0.033	0.023	0.125	0.002	63
S-10G	3.34	1.98	0.33	0.045	0.035	0.033	0.022	0.085	0.000	51
S-14T	3.32	1.95	0.58	0.034	0.022	0.028	0.038	0.411	0.006	
S-15T	3.32	1.95	0.57	0.044	0.020	0.018	0.020	0.204	0.009	38

When the chemical composition of the produced cast iron was analyzed it can be stated that carbon content was changing from 2.84 to 3.70% C, and silicon content from 1.80 to 2.24% Si. All the melted irons are hypoeutectic. The eutectic saturation factor values (Sc) for the melts are presented in Table 7. The phosphorus content in synthetic cast iron was lower than for melts based on pig iron (some departure from the rule are visible for petroleum coke KN4 and cupola coke KO) when this element significant increase appeared. The similar situation occurs for sulfur. Except of those two mentioned melts its content is at the very low level 0.02-0.04%S. This proves that when the petroleum coke or cupola coke is used as carburizer the sulfur content in cast iron significantly increases. When absolute values of this increase are analyzed they seem not to be high (0.015-0.025% S only). However, when compare the melts based on pig iron to these recarburized with synthetic graphite or even anthracite the sulfur increase is 75-120% so is really high.

Very big differences are visible in nitrogen content, too. This element content increase is particularly visible when the iron is recarburized with petroleum coke (increase up to 166 ppm). The steel scrap used in melting processes contained 100 ppm of nitrogen whilst the pig iron contained 43 ppm of this element. The lowest nitrogen content occurs when the iron is melted on the pig iron base and for recarburization with synthetic graphite. Maximum nitrogen content which is introduced purposely to improve cast iron mechanical properties is around 150-200 ppm [13]. However, a lot of foundries have a more strict limit at 120 ppm of N. It means that when the coke-based carburizers are used continuously it may cause accumulation and increase of the nitrogen content in melted cast iron and as a consequence may cause its mechanical properties decrease and gaseous porosity in produced castings.

For some part of the melts the oxygen, nitrogen and hydrogen content in cast iron analysis was made with use of high-temperature extraction method. The results of the measurements are presented in Table 4 and in Figs. 1 and 2.

Table 4.
Hydrogen, nitrogen and oxygen content in cast iron

Melt No.	H ppm	N ppm	O ppm
A2-7N	2.5	83	91
GN-8G	1.7	66	35
GS2-3T	2.2	63	39
GS4-6N	2.1	66	40
KN3-4T	2.9	63	79
KN4-6T	2.4	106	55
KN5-4N	1.8	83	37
WD-12T	3.4	54	82
KO-8N	3.5	127	78
S-10G	1.8	51	45
S-15T	2.2	38	66

When the recorded measurements are analyzed together with the elements analyzed in cast iron melted on pig iron base it may be stated that hydrogen content is significantly higher in iron recarburized with cupola coke KO, charcoal WD and petroleum coke KN4.

The experiments proved the previously made examinations of the nitrogen content in molten cast iron which is the highest for the cupola coke and petroleum coke. The oxygen content is considerably higher in iron recarburized with charcoal and anthracite. Relatively low content of these elements can be observed in iron recarburized with synthetic graphite.
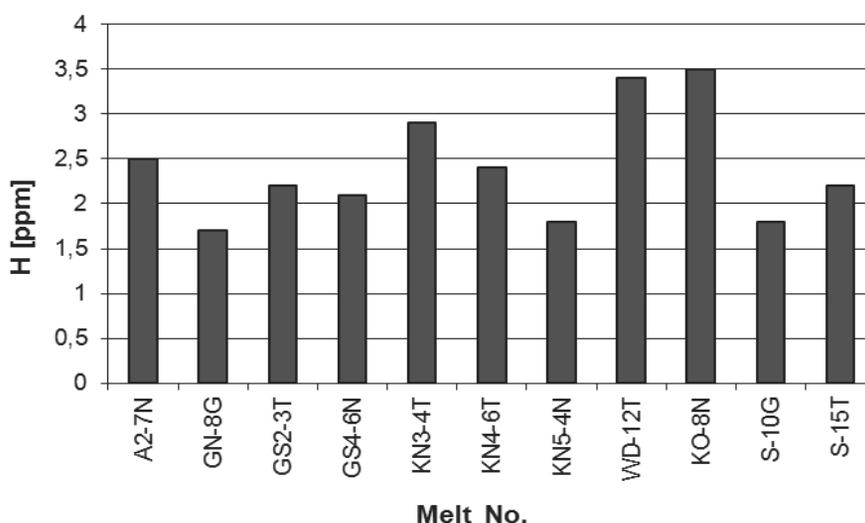

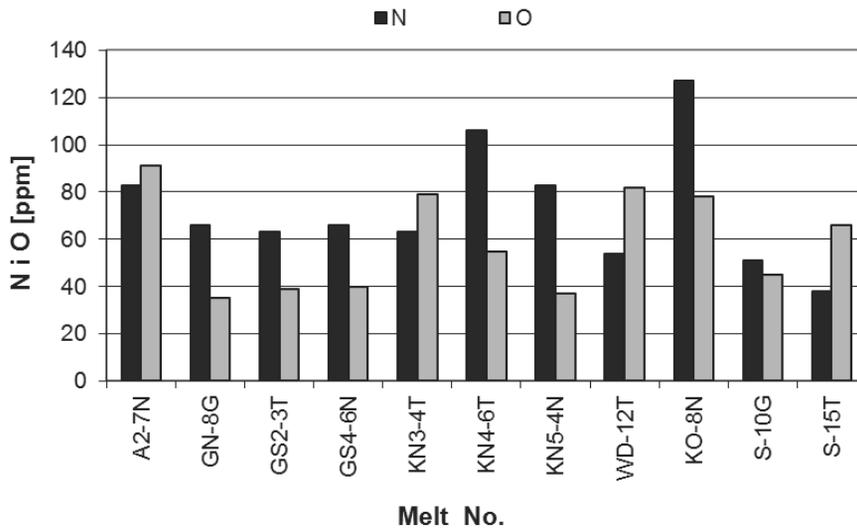Fig. 1. Hydrogen content in produced grey cast iron

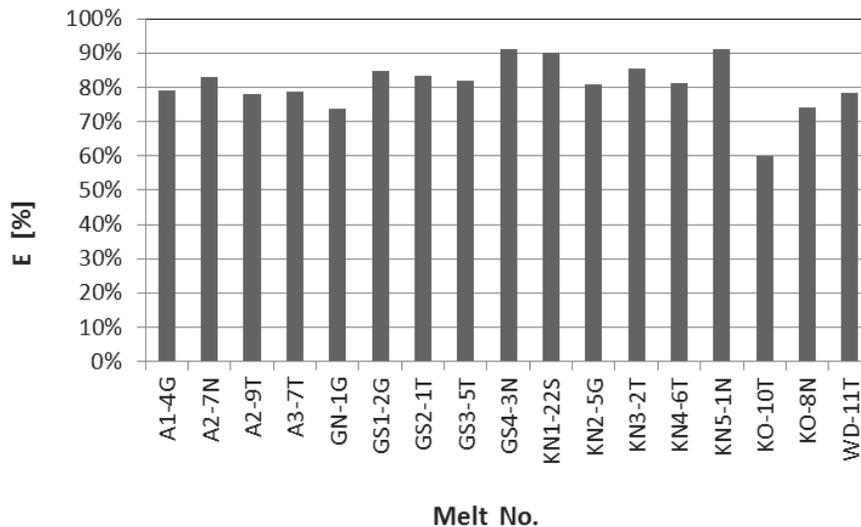Fig. 2. Nitrogen and oxygen content in produced grey cast iron

Fig. 3. Recarburization efficiency for carburizer addition with solid charge

3. Recarburization efficiency

The important issue in recarburization process is carbon assimilation by liquid metal. It depends on many factors i.e. recarburization method, liquid bath temperature, recarburized alloy chemical composition and type of carburizer, too. For the melts described in the article the recarburization efficiency was calculated for various types of carburizers added to the solid charge. Stability of the melting conditions and chemical composition of the charging materials causes that decisive influence on the recarburization efficiency has in this situation carburizer type [14, 15]. For the particular melts the recarburization efficiency was calculated according to the formula:

$$E = M_m \frac{C_k - C_p}{M_n \cdot C_n} \cdot 100\% \qquad (1)$$

where: M_m metallic charge mass, M_n - carburizer mass, C_p - initial carbon content in charging materials or liquid metal (before recarburization), C_k - final carbon content after recarburization process, $\Delta C = (C_k-C_p)$ - carbon increase in liquid bath after carburizer introduction, C_{mn} - carbon content in carburizer.

The recarburization efficiency calculations results are presented in Table 5 and in Fig. 3.

Table 5.
Recarburization efficiency for carburizer addition with solid charge

Carburizer type	Mm kg	Mn kg	ΔC %	E %
A1-4G	10.37	0.376	2.63	78.9%
A2-7N	10.38	0.426	3.22	83.0%
A2-9T	11.47	0.52	3.34	77.9%
A3-7T	11.57	0.52	3.39	78.8%
GN-1G	10.2	0.42	2.58	73.8%
GS1-2G	10.22	0.361	2.96	84.7%
GS2-1T	14.15	0.522	3.05	83.3%
GS3-5T	11.59	0.44	3.09	82.0%
GS4-3N	11.5	0.44	3.47	91.2%
KN2-5G	10.32	0.385	2.95	80.8%
KN3-2T	14.12	0.522	3.13	85.4%
KN4-6T	11.57	0.45	3.13	81.1%
KN5-1N	11.46	0.44	3.48	91.0%
KO-10T	11	0.515	2.47	60.0%
KO-8N	10.22	0.525	3.34	74.0%
WD-11T	11	0.59	3.49	78.5%

The recarburization efficiency varied from 60 to 91% during the experiments. The lowest carbon assimilation rate was 60% and was obtained for cupola coke KO-10T. Such low efficiency for this material is caused by fact that cupola coke was in form of much coarser lumps than any other carburizer used. So, part of these lumps did not dissolute before they floated to the liquid metal surface because the recarburization process proceeded very slow. Very high porosity of the coke and its low specific gravity cause that despite intensive liquid metal movement inside the furnace, the carburizer remains on surface and its contact with molten metal is minimal. For other materials the recarburization efficiency is very high and varies from 75 to 91%. However, it should be emphasized that despite for the anthracite the efficiency was 69-83%, this material dissolves much slower and after the solid charge is completely molten some particles float to the surface. In such a case the complete carburizer dissolution requires additional time and higher liquid metal temperature. The synthetic graphite dissolves best. After the solid charge is melted down there are virtually no carburizer particles on the liquid bath surface.

When compare the different recarburization methods it can be stated that in inductive furnaces carburizer addition into solid charge is the best to obtain high carbon content increase. This method does not require additional devices or equipment.

4. Mechanical properties of the cast iron

The important obtained cast iron quality index is its strength and hardness. Therefore from each melt the standardized cylindrical samples according to EN 1561:1997 standard were cast. Then the samples were broken on strength testing device whilst hardness was tested on Brinell's hardness tester. The results of both examinations were listed in Table 6.

The analysis of these results shows that produced cast iron has an ultimate tensile strength over 200 MPa and hardness over 150 HB. So, the results prove that the cast iron can be produced on the steel scrap base only with carburizers addition without problems and with high mechanical properties of final alloy. The majority of the alloys obtained was classified as class 250 and 300 grey cast iron.

Table 6.
Cast iron strength and hardness tests results

Melt No.	R_m MPa	HB
A1-18S	297.5	180
A2-9T	291.0	170
A2-7N	310.4	211
A3-8T	292.8	170
GN-9S	276.6	207
GS1-21S	307.3	176
GS2-3T	319.1	255
GS2-1T	244.3	223
GS3-5T	305.6	229
GS4-6N	304.8	237
GS4-3N	188.6	170
KN1-22S	257.8	195
KN2-27S	231.4	180
KN3-4T	311.1	229
KN3-2T	257.0	207
KN4-6T	306.4	241
KN5-4N	362.9	237
KN5-1N	285.7	201
WD-12T	329.5	217
KO-13T	353.3	241
KO-8N	313.5	233
S-26S	237.3	176
S-14T	296.0	217
S-15T	278.5	197

Table 7.
Theoretical and real (measured) tensile strength

Melt No.	Sc %	LJ	R_{mt} (Collaud)	R_{mt} (Heller)	R_{mt} (chemical comp.)	R_m MPa
A1-18S	0.99	1.52	204.5	215.5	168.8	297.5
A2-9T	0.97	1.51	221.9	231.0	197.9	291.0
A2-7N	0.96	1.28	231.0	239.1	207.2	310.4
A3-8T	0.87	1.30	305.5	313.4	248.9	292.8
GN-9S	0.99	1.23	205.1	216.4	175.0	276.6
GS1-21S	0.97	1.56	216.6	226.7	179.1	307.3
GS2-3T	0.90	0.99	279.9	287.9	231.4	319.1
GS2-1T	0.92	0.89	264.2	271.3	217.9	244.3
GS3-5T	0.91	1.06	272.9	281.2	229.5	305.6
GS4-6N	0.94	1.08	246.3	256.2	219.4	304.8
KN1-22S	0.96	1.16	225.9	234.7	197.8	257.9
KN2-27S	0.90	1.02	273.9	282.1	228.3	231.4
KN3-4T	0.91	1.08	272.4	281.3	228.6	311.1
KN3-2T	0.93	1.03	252.9	261.9	212.5	257.0
KN4-6T	0.92	1.03	261.4	271.7	229.5	306.4
KN5-4N	0.89	1.19	290.4	297.1	240.1	362.9
KN5-1N	0.95	1.22	232.3	243.7	202.8	285.7
WD-12T	0.87	1.15	304.8	310.9	253.0	329.5
KO-13T	0.84	1.08	328.3	334.4	272.9	353.3
KO-8N	0.99	1.25	201.7	211.9	189.6	313.5
S-26S	0.91	1.08	269.6	278.0	223.7	237.3
S-14T	0.91	1.10	269.8	277.4	232.0	296.0
S-15T	0.91	1.14	269.3	276.7	231.1	278.5

The cast iron tensile strength can be obtained as a result of the direct measurement (strength test described earlier) or estimated approximately with formulas where the ultimate tensile strength value R_m depends on eutectic saturation factor value Sc and hardness HB.

The eutectic saturation factor Sc (see Table 7) can be calculated using formula [6,16]:

$$S_C = \frac{\%C_{measured}}{\%C_{eutectic}} \quad (2)$$

According to Patterson this formula is written as [16]:

$$S_C = \frac{\%C}{4.23 - 0.312 \cdot \%Si - 0.275 \cdot \%P} \quad (3)$$

He proposes a formula for eutectic saturation factor calculation, too [17]:

$$S_C = \frac{\%C}{4.3 - 0.33 \cdot (\%Si + \%P)} \quad (4)$$

However, Collaud proposes another formula [17]:

$$S_C = \frac{\%C}{4.26 - 0.31 \cdot \%Si - 0.33 \cdot \%P - 0.40 \cdot \%S + 0.027 \cdot \%Mn} \quad (5)$$

The particular elements influence on the eutectic point position on the equilibrium Fe-C phase diagram is not completely the same as their influence on the mechanical properties of the alloys produced. In fact, such dependence is visible for grey cast iron only. Most of regression formulas created after statistical analysis of recorded data concern $R_m = f(S_c)$ function. These formulas are mostly linear ones with the only numerical factors different [18,19,20]:

Heller and Jungbluth propose the relation:

$$R_{mt} = 1020 - 825 \cdot S_C \quad (6)$$

However, Collaud's version is:

$$R_{mt} = 1006 - 800 \cdot S_C \quad (7)$$

The ultimate tensile strength according to Weis and Orths [17] can be calculated regarding to chemical composition, too:

$$R_{mt} = 802 - 153 \cdot \%C - 48 \cdot \%Si + 46 \cdot \%Mn + 223 \cdot \%S \quad (8)$$

The mentioned above equations allow to calculate (with ±30 MPa accuracy) the average tensile strength of grey iron with known chemical composition (known S_c value) for the sample machined from standardized rod of Ø 30 × 300 mm, cast regarding to PN-EN 1561. Such calculated strength value is called theoretical strength R_{mt}, to distinguish it from real tensile strength

value R_m, which can be only obtain after tensile test is carried out [16]. The maximum tensile strength value can be estimated on the HB hardness value, too.

The authors of many articles introduce for cast iron quality evaluation the LJ index (proposed by Patterson), which can be calculated from equation [16,17]:

$$LJ = \frac{R_m}{HB} \cdot \frac{539 - 355 S_C}{1020 - 825 S_C} \quad (9)$$

For the cast iron of good quality LJ index should be at least LJ=1.00. According to Patterson only for cast iron refined with gases this index is as high as 1.2, whilst for the ductile cast iron it reaches 1.5 [16]. The eutectic saturation factor Sc and cast iron quality index LJ values were presented in Table 7 below.

The alloys quality analysis was carried out for the synthetic cast iron (on the steel scrap base only) as well as for the melts made on pig iron base. The theoretical tensile strength R_{mt} and real tensile strength R_m values were presented in Table 7, too. In brackets there was mentioned which formula was used to calculate particular values. Fig. 4 presents the graphical comparison of these values.

When the calculations results are being analyzed they show that for the cast iron recarburizer with petroleum coke KN2, synthetic graphite GS2-1T and iron melted on the pig iron base S-26S, the measured values of the tensile strength are slightly lower than the calculated ones. For the rest alloys the real strength is higher than the theoretical one, calculated with use of different formulas. The real and theoretical strength ratio of the iron recarburized with anthracite is much higher than for these recarburized with other carburizers or produced on the pig iron base. This situation is similar for A1 and A2 anthracite.
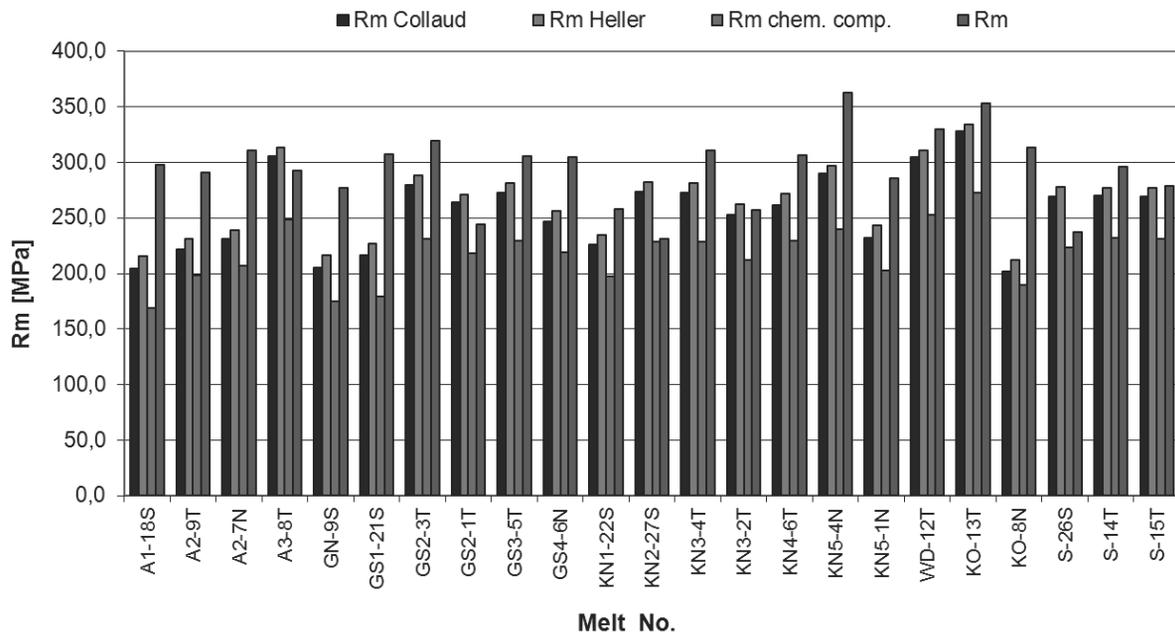

Fig. 4. Theoretical and real (measured) tensile strength

When the cast iron quality index LJ (so-called Patterson's index) is being analyzed it can be stated that for all melts recarburized with anthracite this parameter is significantly higher than 1. Its values are in range 1.28-1.52, which according to Patterson are reachable only for cast iron refined by gases or ductile cast iron. For other carburizers used the only single values higher than 1.28 appear but without repeatability. Additionally it is visible that the quality index LJ for the anthracite as carburizer is considerably higher than for cast iron produced on the pig iron base. For the analyzed range of the experiments the hypothesis may be formulated that the carburizer type influences the produced cast iron quality and from this point of view the best one is the anthracite. It may be caused by fact that in cast iron recarburized with the anthracite more flake graphite precipitations appear and they are smaller (length, circumference, width and ratio of circumference and surface) than in cast irons recarburized with other carburizers or melted on the pig iron base.

5. Conclusions

On the carried out researches and calculations base which were only partly presented in this article some conclusions can be formulated as below. The experiments proved that the synthetic cast iron can be melted on the steel scrap and the carburizers base. The recarburization efficiency obtained when the carburizer was added with solid charge in inductive furnace varied from 70 to 96% (for experiments described here this efficiency is between 60 and 91%). Actually, for every carburizer the recarburization efficiency can be achieved at over 80% level with very good repeatability when some crucial melting process parameters are correct.

The synthetic cast iron produced in that way contains less impurities such sulfur and phosphorus. The best carburizers from the chemical composition point of view (carbon content) and recarburization efficiency are synthetic graphite and petroleum coke. When the anthracite is used it is possible to achieve high efficiency but only when the liquid metal is heated up to higher temperature and dissolution time is longer.

The chemical composition analysis shown that petroleum coke can contain significant nitrogen content what may cause this element in iron increase and after 120-150 ppm level is exceeded the mechanical properties of the alloy may lower as a consequence of that. Higher hydrogen and oxygen concentration occur in cast iron recarburized with the anthracite, charcoal and cupola coke.

When tensile strength and hardness of cast iron is being analyzed it may be stated that they are over 200 MPa for strength and over 150 HB for hardness. These results indicate that cast iron can be melted only on steel scrap base and carburizers with no special efforts and high mechanical properties are secured. On this stage of researches when results are linked to the carburizer type it is clearly visible that high and repeatable strength was obtained for the cast iron recarburized with the anthracite.

When the cast iron quality index LJ is being analyzed it can be stated that only for the melts with synthetic graphite GS2 recarburization and iron recarburized with carburizer SA1 (acetylene synthesis product) the LJ value was below 1. For the rest of the melts this factor is over 1 what means that the produced cast iron was of good quality. Moreover, for the anthracite the factor is very high in each melt. It exceeds 1.28 which characterizes cast iron refined with gases or ductile cast iron.

Summing up in authors' opinion the hypothesis may be formulated that the heredity phenomenon in alloys occurs [21,22,23,24]. This is proved by very high quality index LJ and high and uniform strength of cast irons recarburized with the anthracite. This is probably cause by fact that in cast iron recarburized with the anthracite exist significantly lower graphite precipitations (in terms of length, circumference, width and ratio of circumference and surface) than in cast iron recarburized with other carburizers or melted on the pig iron base. The changes observed in the microstructure do not cause of its degradation and alloy properties decrease. Quite the opposite, they cause the quality parameters increase and make possible to produce the cast iron of higher strength with the same chemical composition when the proper carburizer is employed.

References

[1] K. Janerka, D. Bartocha, J. Szajnar, J. Jezierski, The carburizer influence on the crystallization process and the microstructure of synthetic cast iron, Archives of Metallurgy and Materials 55/3 (2010) 851-859.

[2] K. Janerka, D. Bartocha, J. Jezierski, J. Szajnar, The effect of the carburiser quality on the cast iron recarburisation process, Foundry Trade Journal International 184/3679 (2010) 282-286.

[3] K. Janerka, D. Bartocha, J. Szajnar, M. Cholewa, The influence of different kind of carburizers and carburization on the effectiveness and iron structure, Archives of Metallurgy and Materials 52/3 (2007) 467-474.

[4] K. Janerka, D. Bartocha, J. Szajnar, Quality of carburizers and its influence of carburization process, Archives of Foundry Engineering 9/3 (2009) 249-254.

[5] M. Gagne, The Sorelmetal book of ductile iron, Sorelmetal Technical Services, 2006.

[6] T. Wróbel, Bimetallic layered castings alloy steel - grey cast iron, Archives of Materials Science and Engineering 48/2 (2011) 118-125.

[7] K. Janerka, J. Jezierski, J. Szajnar, The evaluation of effectiveness of liquid cast iron recarburization process by using different carburizers and methods of recarburization, 20th Anniversary International Conference on Metallurgy and Materials (METAL), Brno, Czech Republic, May, 18-20, (2011) 156-162.

[8] J. Jezierski, D Bartocha, Properties of cast iron modifying with use of new inoculants, Journal of Achievements in Materials and Manufacturing Engineering 22/1 (2007) 25-28.

[9] C. Podrzucki, Cast iron - microstructure, properties and applications, Publisher ZG STOP, Cracow, 1991 (in Polish).

[10] M. Perzyk, S. Waszkiewicz, M. Kaczorowski, A. Jopkiewicz, Castings, WNT, Warsaw, 2000 (in Polish).

[11] E. Fraś, Metals crystallization, WNT Warsaw, 2003 (in Polish).

[12] K. Janerka, D. Bartocha, J. Szajnar, The carburization process rates in synthetic cast iron production, Journal of Achievements in Materials and Manufacturing Engineering 18 (2006) 379-382.

[13] F. Wilberfors, I.L. Svensson, The effect of nitrogen and inoculation on the tensile properties and microstructure of cast iron with lamellar graphite, Key Engineering Materials, 457 (2011) 114-119.

[14] K. Janerka, The rate of effectiveness of carburization to the sort of carburizer, Archives of Foundry Engineering 7/4 (2007) 95-100.

[15] K. Janerka, D. Bartocha, J. Szajnar, Carburization process rate in production of synthetic cast iron, Archives of Materials Science and Engineering 36/1 (2009) 55-61.

[16] W. Łybacki, The quality of the synthetic cast iron produced in plasma-inductive furnace, Solidification of Metals and Alloys 43/2 (2000) 337-342 (in Polish).

[17] W. Łybacki, Quality of synthetic cast iron manufactured in plasma-induction furnace, Mechanics 55/5 (2005) 62-64.

[18] W. Patterson, R. Döpp, Standards of the cast iron with flake graphite evaluation, Giesserei 60/2 (1973) 32 .

[19] M.M. Jabbari Behnam, P. Davami, N. Varahram, Effect of cooling rate on microstructure and mechanical properties of gray cast iron, Materials Science and Engineering A 528/2 (2010) 583-588.

[20] T. Sjögren, H. Svensson, Study of the eutectoid transformation in grey cast irons and its effect on mechanical properties, Key Engineering Materials 457 (2011) 157-162.

[21] W.J. Nikitin, The perpectives of the genetic engineering in alloys, Litejnoje Proizwodstwo 1 (1999) 5-9 (in Russian).

[22] W. Gawrilin, The mechanism of liquid cast alloys creation and their heredity, Litejnoje Proizwodstwo 1 (1999) 10-12 (in Russian).

[23] B.F. Trachtenberg, M.S. Kenis, W.I. Krestianow, L.W. Troszyna, Diagnosis of the basic mechanisms of the technological heredity, Litejnoje Proizwodstwo 1 (1999) 13-15 (in Russian).

[24] W.I. Krestianow, Structural heredity during the ductile iron castings production, Litejnoje Proizwodstwo 1 (1999) 18-20 (in Russian).