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The rate and effectiveness of carburization to the sort of carburizer

K. Janerka*
Department of Foundry, Silesian University of Technology , Towarowa St 7, 44-100 Gliwice, Poland
*Corresponding author. E-mail address: krzysztof.janerka@polsl.pl

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Abstract

The obtaining of demanded carbon contents during melting the cast iron with bounded pig iron's portion is important problem for many foundries. There are searched the effective methods and carburizers, which would ensure obtaining of big carbon increases with great repeatability as quick as possible. The aim of presented researches was definition of influence of essential factors characterized the carburization and the sort of carburizer on the rate and effectiveness of process. The cast iron melts are presented only on the basis of steel scrap with the portion of graphitoidal, coke and anthracite carburizers. Two methods of carburization are taken into consideration during the experiments were carried out: the addition of carburizer to charge in solid in the initial period of melting and addition of carburizer on surface of liquid metal . The obtained researches results and their analyze allow to choose the corresponding method and the sort of carburizer. One can state, that the best carburizer is synthetic graphite, if the rate and effectiveness of process is considerate and the best method of carburization in the electric inductive furnace is addition of carburizer to charge in solid. In the subsequent part of researches the analyze of influence of carburizer on the structure of grey cast iron and ductile cast iron. The initial researches has showed the differences in obtained structures of synthetic cast iron melted only on the basis of steel scrap and defined kind of carburizer.

Keywords: Theoretical bases of foundry processes, Cast iron, Carburization, Carburizers, Rate of carburization

1. Introduction

The matter of carbon melting rate in liquid alloys and the effectiveness of carbon assimilation by metal bath (the effectiveness of carburization) is still very important. There are searched the new methods, which will allow to reduce the costs of production by keeping their quality high simultaneously. It is visible in charge materials when more expensive materials are replaced by the cheaper ones (steel scrap), moreover partially or whole pig iron from charge material are eliminated. In iron melting it caused that carbon deficiency in liquid alloy comes into being yet and it created the necessity of its addition. In foundry engineering are still searched the new methods and carburizers secured gaining demanded increases of carbon as quick as possible very high repeatability few methods of liquid metal carburization in electric arc and induction furnaces exist as well. They include: addition of carburizer to charge in solid, addition of carburizer on surface of liquid metal, addition of carburizer at the bottom of ladle during pouring the metal out of the furnace, addition on the tapped gutter as well as introduction of carburizer in the stream of carrier gas [1,2,3,4]. The method of pneumatic carburization found wide application in electric path furnace, where the stream carrying the carburizer forces the movement of metal bath, which make the mass exchange more intense. From many years the Department of Foundry of Silesian University of Technology has been carrying out the experiments of pneumatic carburization of liquid iron alloys in laboratory and industrial conditions [5,6]. In these researches one paid particular attention to rate and effectiveness of process and the influence of dosing devices' parameters of flow, e.g. the intensity of gas and material, the velocity of stream on these carburization parameters [7]. They decide about the time of melting and as a consequence – about the costs of production. The big influence on the rate and effectiveness of the carburization have the temperature of liquid metal and the initial carbon contents in alloy. The sort of used carburizer is also important (natural and synthetic graphite, anthracite, coke, petroleum coke). Materials used in foundry engineering should have high carbon contents and marginally amounts of impurities as ash and sulphur as well as low nitrogen and hydrogen contents [8,9]. In many research works the influence of impurities and sort of the carbon material on the rate of process and the coefficient of exchanging mass is also analyzed [10,11,12]. On the basis of these researches it was found that the impurities in carburizer reduce the level of carbon assimilation, increase the amount of nascent cinder as well as they cause deterioration of obtained alloys quality. They also reduce the rate of process and the coefficient of exchanging mass. The results obtained in researches which were carried out, testify the significant reaction of the sort of carburizer on rate and effectiveness of process and one showed that as the rate of carburization is on the increase, the effectiveness of process getting low.

Carburization effectiveness expressed in % and defined by equation:

$$E = M_m \frac{C_k - C_p}{M_n C_x} \cdot 100\% \tag{1}$$

where: M_m – solid material mass in kg, M_n – carburizer mass in kg, C_p – initial carbon content in solid or liquid metal (before carburization) in %, C_k – final carbon content after the carburization in %, C_x – carbon content in carburizer in %.

Taking into account course of component change between two phases phenomena, often the boundaries layers model of Nerrst are used. In many works the equations presenting rate of carburization are cited of [13,14]:

$$\frac{dC}{dt} = \frac{D_c}{\delta} \cdot \frac{F}{V}(C_{max} - C) = k_c(C_{max} - C) \tag{2}$$

where: C–carbon concentration in liquid metal in %, C_{max}–carbon concentration adequate for saturated state in given conditions in %, D_c –diffusion coefficient in $m^2 s^{-1}$, F–phases adjacent surface in m^2, V–volume of phase in which component contents is changing in m^3, δ - thickness of boundary diffusion layer in m, k_c–mass transfer between carburizer and liquid metal coefficient (carburization constant).

The Department of Foundry is also carrying out the experiments, which are to define the influence of carburizer on structure and properties of obtained synthetic cast iron [15,16].

2. The addition of carburizer to charge in solid

Within the framework of researches realization some experiments of metal carburization by addition of carburizer to charge in solid with using natural and synthetic graphite, anthracite A and B with different carbon content, petroleum coke A. In the petroleum coke A its surface was activated by organic compounds to obtain higher rates and effectivenesses of process. This material occurs in researches as the petroleum coke B. The chemical constitution and the sort of materials used in researches are presented in the Table 1. The carburization place in melting pot of induction furnace with the frequency of capacity about 20 kg.

Table 1
Carburizers used in researches

Sort of material	C [%]	S [%]	Ash [%]
natural graphite	85	0,08	11,0
synthetic graphite	99,1	0,30	0,4
anthracite A	92	0,30	4,0
anthracite B	95	0,30	4,0
petroleum coke A	98	0,50	0,6
petroleum coke B	98	0,50	0,6

In the initial melts the essential ingredients of charge for each of carburizing materials were the steel scrap with the carbon contents of 0,1% and the carburizer. These ingredients were loaded into the induction furnace in weighed portions: 12,9 kg of steel scrap and 0,085-0,100 kg of carburizer (diversity in amount of loaded carburizer was caused by the necessity of obtaining similar carbon increases in liquid metal). After the furnace had been became loaded the process of melting was begun. After melting the measurement of temperature was done and the sample was taken to the chemical analyze of carbon and sulphur on the LECO device. The results obtained from analyze, amount of solid materials as well as obtained carburization effectiveness are presented in table 2 below.In the rest of melts the essential ingredients of solid was the material obtained from previous melt and carburizer. Three attempts were carried out by addition of carburizer to charge in solid for every material. On the basis of obtained measurements' results one can state that the method of addition the carburizer to charge in solid allows to obtain very high effectivenesses of carburization. The average carburization effectiveness ($E_{śr}$) amounted to almost 99% for synthetic graphite, for petroleum coke with the activated surface 95%, for petroleum coke 90% and for anthracites 94 to 95%. The lowest effectiveness was obtained for natural graphite. This material contains big amounts of ash and probably it is the reason for obtaining such a low indexes. It confirms the results of researches presented in the literature which was quoted earlier. During the tracing of table one can also notice that for every melt with the carbon contents amounted to 0,1%C in metal charge, the obtained effectiveness totaled to over 96%. It also confirms the results, which are included in the literature, concerning the decrease of process's parameters by the increase of carbon contents in metal bath. The change of effectiveness to the function of initial carbon contents in charge is presented on Figure 1. One can notice that that influence is the most visible for natural graphite and the least by using the synthetic graphite as a carburizer.

Table 2.
The results of metal bath carburization by the addition of carburizer to charge in solid

Sort of material	No. of melt	M_m	M_n	C_p	C_k	ΔC	E	E_{av}
natural graphite	1	12,9	0,100	0,1	0,740	0,64	97,13	80,73
	2	12,51	0,100	1,17	1,67	0,5	73,59	
	3	12,15	0,100	2,11	2,61	0,50	71,47	
synthetic graphite	4	12,92	0,085	0,1	0,751	0,651	99,85	98,99
	5	12,22	0,085	1,35	2,035	0,685	99,37	
	6	11,80	0,085	2,55	3,24	0,69	97,74	
anthracite A	7	12,92	0,090	0,1	0,719	0,619	96,59	84,37
	8	10,62	0,090	1,14	1,76	0,62	79,52	
	9	10,45	0,090	2,21	2,82	0,61	76,99	
anthracite B	10	12,91	0,085	0,1	0,715	0,615	98,32	85,21
	11	13,06	0,085	1,09	1,58	0,49	79,25	
	12	13,00	0,085	1,99	2,48	0,49	78,08	
petroleum coke A	13	12,91	0,085	0,1	0,744	0,644	99,81	90,58
	14	12,65	0,085	1,29	1,88	0,59	89,60	
	15	12,47	0,085	2,41	2,96	0,55	82,33	
petroleum coke B	16	12,92	0,085	0,1	0,745	0,645	99,03	94,72
	17	13,17	0,085	1,36	1,99	0,630	99,61	
	18	12,5	0,085	2,39	2,96	0,570	85,53	

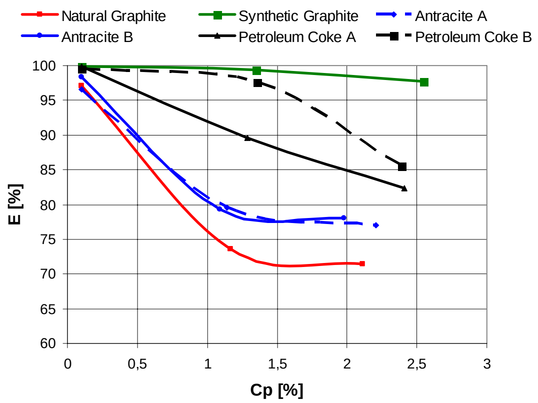

Fig 1. The influence of initial carbon contents on effectiveness

3. The addition of carburizer on the surface of metal bath

In these melts the essential ingredients of charge were process scrap of carbon contents from 0,71 to 3,24%C and carburizers. After the metal had been melted, the measurement was carried out, the cinder was taken away and next the carburizing material was poured (in measured portions from 0,085 to 0,100 kg for every single carburizer) on the surface of metal bath. The samples were taken to the chemical analysis of carbon on the LECO device in the regular intervals of time (1,2 or 3 minutes). The process was ended when the carburizer being on the surface of metal's mirror was completely melted. During the carburization the parameters of furnace work was setting on the values ensured keeping constant temperature of metal bath. The obtained results of chemical analyzes, weight burden of charge materials and the obtained effectiveness of carburization are presented in the Table 3. The results of carburization rate (R_{av}) calculation, defined by the ratio of carbon increase in the metal bath to the carburization time measured from the moment of taking the sample are also included in this table.

The value is averaged and it depends on the amount of drawn samples during the realization of experiment. It is expressed in $\%/s \cdot 10^{-3}$.

For each of carburizing material there are run the graphs (fig 2 to 13) of change in carburization rate and effectiveness in the function of time measured from the moment of addition the carburizer to drawing the samples to chemical analysis for different initial carbon contents C_p in liquid metal.

By analyzing the obtained effectiveness's one can state that they are considerably lower than those obtained in the method of addition the carburizing material to charge in solid. This decrease amounted to 15 to 20% at the average. The highest effectiveness's were obtained for the petroleum coke and synthetic graphite, then for anthracite and natural graphite. One should point out that the increase of effectiveness is function of time and it depends on carburizer which were used. The increase is the highest for synthetic graphite, then for the petroleum coke with activated surface, for anthracite and natural graphite. The time of completely carbon assimilation changed from 4 to 8 minutes.

Table 3
The results of researches and calculations of carburization by addition the carburizer on the surface of liquid metal's mirror

Sort of material	No. of melt	M_m	M_n	C_p	C_k	ΔC	E	E_{av}	R_{av}
natural graphite	1	12,9	0,100	0,740	1,170	0,430	65,26	65,73	1,21
	2	12,51	0,100	1,67	2,11	0,44	64,76		1,23
	3	12,15	0,100	2,61	3,08	0,47	67,18		1,49
synthetic graphite	4	12,92	0,085	0,751	1,35	0,599	91,87	77,48	4,12
	5	12,22	0,085	2,035	2,55	0,515	74,71		3,01
	6	11,80	0,085	3,24	3,71	0,47	65,84		1,53
anthracite A	7	12,92	0,090	0,719	1,14	0,421	65,69	63,43	2,55
	8	10,62	0,090	1,76	2,21	0,45	57,72		2,11
	9	10,45	0,090	2,82	3,35	0,53	66,89		1,71
anthracite B	10	12,91	0,085	0,715	1,09	0,375	59,95	69,45	1,61
	11	13,06	0,085	1,58	1,98	0,40	64,69		1,69
	12	13,00	0,085	2,48	3,00	0,52	83,72		1,53
petroleum coke A	13	12,91	0,085	0,744	1,29	0,546	84,62	80,47	2,54
	14	12,65	0,085	1,88	2,41	0,53	80,49		2,28
	15	12,47	0,085	2,96	3,47	0,51	76,35		1,14
petroleum coke B	16	12,92	0,085	0,745	1,36	0,615	95,39	72,38	3,94
	17	13,17	0,085	1,99	2,39	0,400	63,24		1,96
	18	12,5	0,085	2,96	3,35	0,390	58,52		2,10

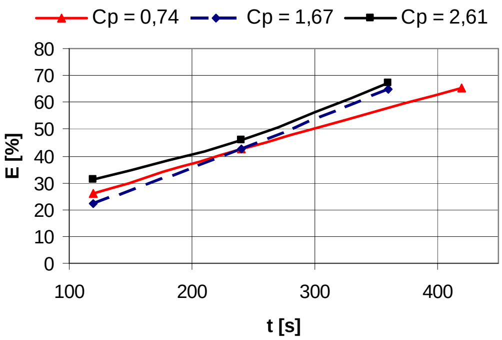

Fig. 2. The carburization effectiveness for natural graphite

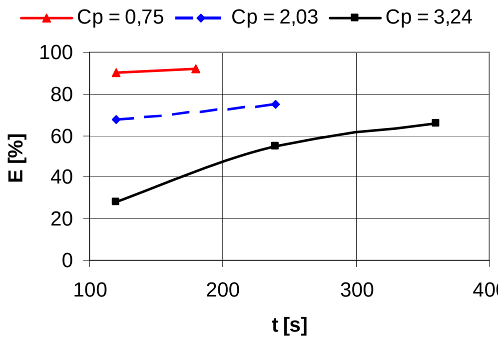

Fig. 4. The carburization effectiveness for synthetic graphite

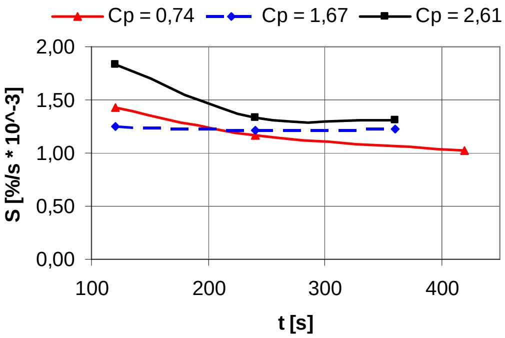

Fig. 3. The carburization rate for natural graphite

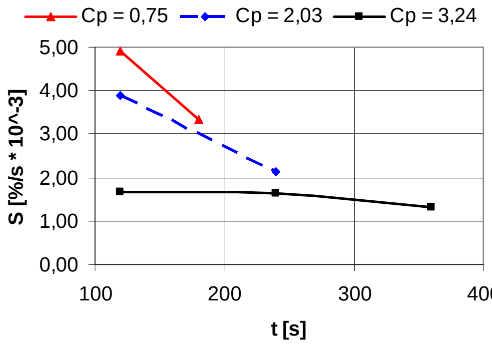

Fig. 5. The carburization rate for synthetic graphite

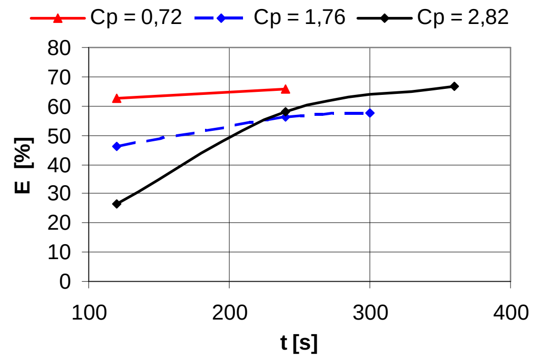

Fig. 6. The carburization effectiveness for anthracite A

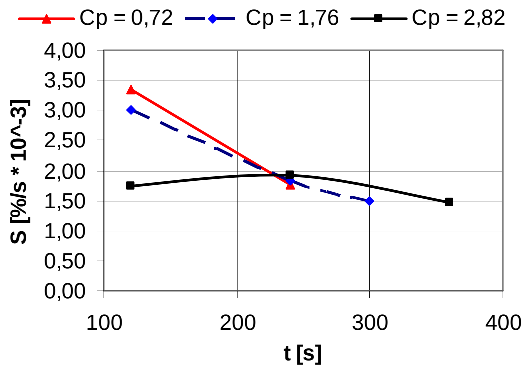

Fig. 7. The carburization rate for anthracite A

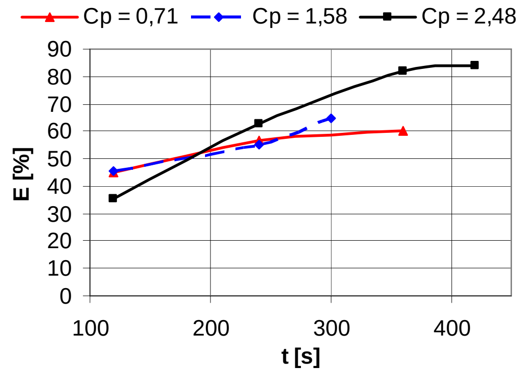

Fig. 8. The carburization effectiveness for anthracite B

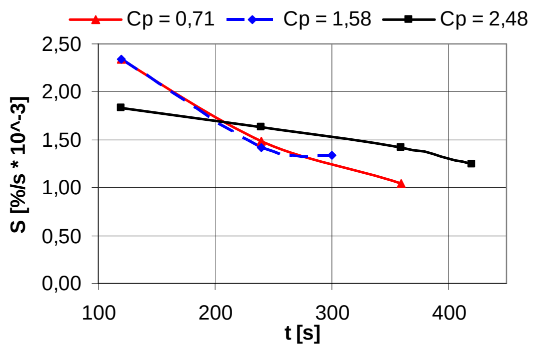

Fig. 9. The rate of carburization for anthracite B

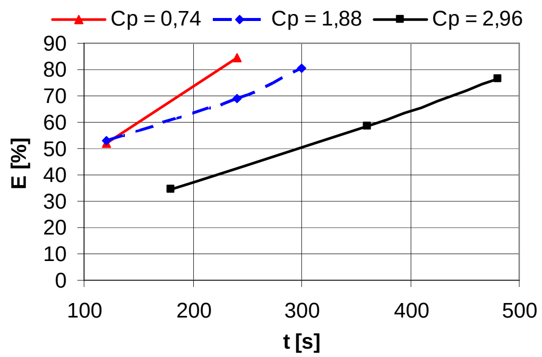

Fig. 10. The carburization effectiveness for petroleum coke A

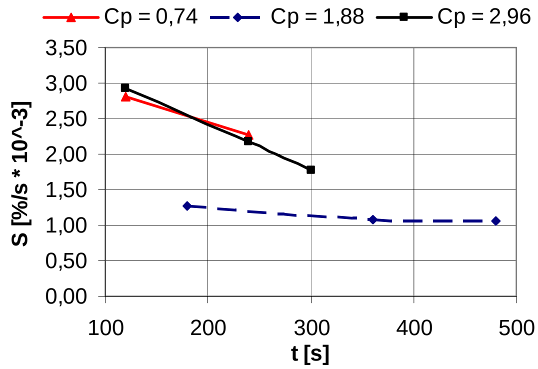

Fig. 11. The carburization rate for petroleum coke A

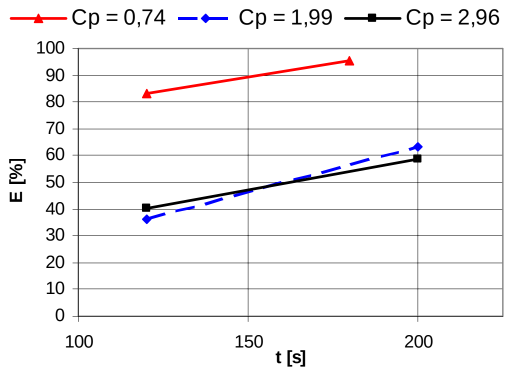

Fig. 12. The carburization effectiveness for petroleum coke B

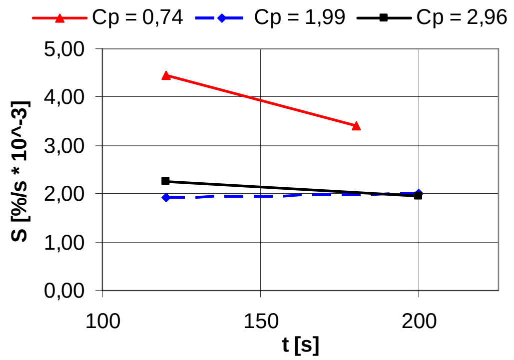

Fig. 13. The rate of carburization for petroleum coke B

By analyzing the influence of initial carbon contents on the carburization effectiveness (Fig. 14) one can state that the decrease of effectiveness with simultaneous increase of carbon contents in liquid metal is visible for synthetic graphite and petroleum cokes. This correctness is impossible to notice for other materials used in the researches.

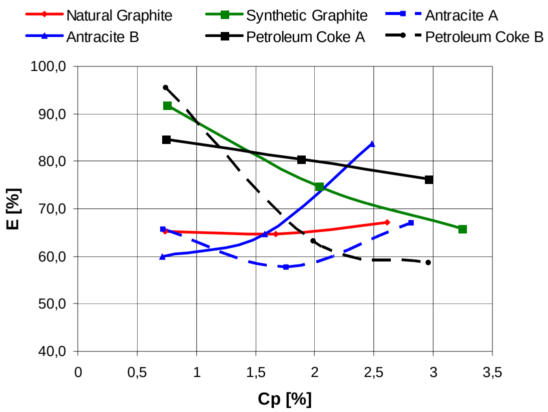

Fig. 14. The influence of initial carbon contents on the carburization effectiveness by the addition of carburizer on the surface

The second parameter which was analyzed in the experiments was the carburization rate (R). The highest values of this parameter were obtained appropriately for synthetic graphite, petroleum coke B, petroleum coke A and anthracite. In every case the decrease of carburization rate in time occurs and it is more or less visible. One can notice considerably bigger values of this parameter by lower initial carbon contents in liquid metal as well.

4. Summary

On the basis of experiments which were carried out one can draw some conclusions concerning the carburization. One can state that considerably more beneficial method of carburization is the addition of carburizer to charge in solid. The carburizer become heated simultaneously with charge and the time of contact between these two materials is very long, what caused high effectiveness. The disadvantage of this method is the fact that we not always know the initial carbon contents in charge and then occurred the problem with the amount of dosed carburizer.

By the addition of carburizer on the surface it is visible that by increase of carburization rate, the effectiveness of process is on the decrease. It means that the addition of bigger amount of carburizer in short time will cause the increase of carburization rate, but the grade of exploited carbon will get reduced. So one should add the carburizer on the surface in smaller portions so that its layer will be thin. It will make the time of process longer, but it will cause the increase of carburization effectiveness. Activating of petroleum coke's surface accelerated the process of carbon melting considerably. However, it did not cause the meaningful increase of carburization effectiveness.

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