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The carburization process rates in synthetic cast iron production

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ABSTRACT

Purpose: The aim of presented researches was determination of possibility of synthetic cast iron production on base of steel and process scrap as well as determination of carburization effectiveness, realized with three methods: addition of carburizer to charge in solid, addition of carburizer on surface of liquid metal, pneumatic injection of carburizer in stream of carrying gas to liquid metal.
Design/methodology/approach: Each of these methods have a undoubted advantages but also have a number of disadvantages. In foundry engineering practice the most essential parameters of this process are to obtain as high as possible degree of carbon assimilation from carburizer, in as short as possible time, with high process repeatability.
Findings: Decrease of share or elimination of the pig iron from charge materials causes significant reduction of cast iron melt costs. Working out the effective and repeatable crburization method is a very important issue.
Research limitations/implications: The result of carburization in arc electric furnaces experiments carried out by the authors of this paper made possibility on application method of pneumatic carburization in a dozen of domestic foundries. Presented below researches concern inductive furnaces, which are a wide group of melting furnaces applied in foundry engineering. Basis on these researches affirmed that the most effectiveness carburization method is the pneumatic injection of carburizer in stream of carrying gas.
Practical implications: This method required significant financial outlay on devices purchase. Considerably cheaper method, but less repeatable is a addition of carburizer to solid charge.
Originality/value: Realized experiments are a part of statutory researches and have not only utilitarian value (worked out effective method for carburization in industrial conditions), but also experience (rate change of carbon content increase in function of time for changeable parameters of liquid metal.
Keywords: Casting; Powder injection; Carburizing

1. Introduction

In foundry engineering are still searched new methods, which make possible decrease cost of castings productions with its high quality keeping at the same time. Appling of new technologies are caused by the still increasing competition and increasing quality and strength requirements, which are put to foundry products. It is visible in charge materials selecting process, when the more expensive materials are replaced by the cheaper ones (steel scrap and process scrap), moreover when the partially or whole pig iron from charge material are eliminated. In such cast iron melting process the carbon deficiency in liquid alloy and the necessity of its addition come into begin. Exist a few methods of liquid metal carburization in electric arc and induction furnaces. This is: addition of carburizer to charge in solid, addition of carburizer on surface of liquid metal, addition of carburizer into tapping spout, addition of carburizer as a cored wire and pneumatic injection of carburizer to liquid metal. Each of these methods has undoubted advantages but also has a number of disadvantages.

In foundry engineering practice the most essential parameters of this process are to obtain as high as possible degree of carbon assimilation from carburizer, in as short as possible time, with high process repeatability.

The results of experiments of carburizing with three carburization methods are presented below:

1. addition of carburizer to charge in solid,
2. addition of carburizer on surface of liquid metal,
3. pneumatic injection of carburizer to liquid metal.

The aim of these researches was determination of possibility of synthetic cast iron production on base of steel and process scrap.

2. Guidelines of researches

Researches were carried out in electric coreless induction furnace with 20 kg capacity. Such furnace makes possible to carry out melts in wide range of temperature and its precision controlling. Therefore in this furnace are get high degree of conditions stability of carburization process, unattainable in other foundry furnaces. Arising rotary currents ensuring intensive mixing of liquid metal without necessary of mechanical mixing. Thanks to intensive metal bath movement carburization process proceeds faster. It connects with decreasing of liquid metal layer adherent to carburizer particle as a result of melt bath rotary. Control of this process intensity is possible thanks to application of furnaces with different power and frequency.

From earned experiences follows that the best carburization coefficients may obtain in graphite inserting process. Therefore in carried experiments scrap of graphite electrodes has been used. It had graphite content on 96% level and very small amount of impurities (ash and sulfur). In experiments graphite with 0-1,6 mm and 5-8 mm granulation has been used. Selected carburizer granulation was dictated by two factors. First follows from fact that theoretical the best results may be obtained using fine carburizers. The big contact surface between liquid metal and carburizer then exists what in consequence causes obtaining high speed of process course. Second factor is possibility of loose materials moving in devices of pneumatic conveying, where the maximum diameter of particles should not exceed 1/3 diameter of conveying pipeline. That's way material with 5-8 mm fraction was not used during pneumatic carburization.

3. Addition of carburizer to charge

Steel scrap with 0,46% carbon content and milled graphite was loaded into crucible of induction furnace. After charge loaded melting process was begun. After melted and reached temperature of 1450^{o}C, the specimen for chemical analysis was taken. The chemical analysis was carried out with LECO devices for carbon and sulfur contents determination. Obtained results of measurements and calculations are presented in table 1.

Essential factor characterizes carburizaton process is carburization effectiveness determined with equation:

$$E = m_m \frac{(C_k - C_p)}{m \cdot C_x} \quad (1)$$

C_p – carbon content at the beginning of the process [%],
C_k – carbon content at the end of the process u [%],
m_m – metal mass [Mg],
m – mass of the carburising material [Mg],
C_x – carbon content in the carburising material [%].

Table 1.
Comparison of results obtained in each melt carburised with addition of solid carburizer onto bottom of furnace.

No of Melt	Fraction [mm]	m_m [kg]	m [kg]	C_p [%]	C_k [%]	E [%]
1.1	0-1.6	11.0	0.15	0.46	1.56	84.9
3.2	0-1.6	11.0	0.15	2.38	3.30	71.0
4.3	5-8	11.0	0.15	0.46	1.27	62.5

In this carburization method effectiveness was changing in range of 62.5-84.9%. The biggest effectiveness has been obtained during carburisation with fine carburizer and 0.46% carbon content at the beginning of the process. Used of carburizer in pieces caused decrease of effectiveness to 62.5%. From the carried out experiments follow that effectiveness significantly decreasing with increasing of carbon content in metal bath at the beginning of the process. This method is a very simple for industrial applications but its basis disadvantage is its low repeatability what in consequence causes necessity of recarburizing of liquid metal with for example addition of graphite on liquid metal surface.

4. Addition of carburizer to metal bath

After melted of metallic charge and reached right temperature (1450^{o}C), the specimen for chemical analysis was taken. Next the weighted portion of carburizer was poured on liquid metal surfaces and specimens for chemical analysis were being taken (with quartz pipe) in specific time interval.

Obtained results of measurements and calculations are presented in table 2.

In this method effectiveness of carburization in range 60.9-91% has been obtained. The biggest effectiveness has been obtained during carburisation by adding pieces of carburizer on liquid metal surface.

Table 2.
Comparison of results obtained in each melt carburised with addition of carburizer on metal bath surface.

No of Melt	Fraction [mm]	m_m [kg]	m [kg]	C_p [%]	C_k [%]	E [%]
1.4	0-1.6	11.0	0.15	1.56	2.59	79.5
2.6	0-1.6	11.0	0.15	1.25	2.23	79.2
3.7	0-1.6	11.0	0.15	3.30	4.09	60.9
4.8	0-1.6	11.0	0.15	1.27	2.45	91.0
4.9	5-8	11.0	0.15	2.45	3.36	70.2

Analysing the influence of carbon content at the beginning of the process on carburisation effectiveness may be affirmed that this factor decreases. Use of fine-grain carburisers cause that on liquid metal surface arise a layer of graphite. Then surface carburizer - liquid metal is decreasing, because only the closest thin layer have contact with metal bath. The others layers come into contact with liquid metal after solubilize the first layer. Melt's duration in this method lengthened even with 100%. Because time of waiting for graphite material solubilization lengthening. Some acceleration may be obtained by the mechanical melting of liquid metal but in industrial applications this is difficult for significant depth of induction furnaces reason.

5. Pneumatic injection of carburizer

Inserting of fine-grain carburizing material in stream of carrying gas causes that obtaining surface of carburizer-liquid metal contact is very big, in that reason process's speed and effectiveness are very high. But it requires the knowledge about diphase stream flow [1, 2]. In addition carrying gas mixes liquid metal and carburizing products are very fast carry off the reaction zone. Moreover movement of carburizer particles causes that the thickness of diffusion layer decreases what in consequence accelerates process of mass exchange between carburizer and liquid metal [3-9]. Advantages mentioned above cause application of pneumatic injection of carburizer to liquid metal method for electric arc furnaces in many polish foundries [10, 11].

Usefulness of pneumatic carburization of liquid metal method may be considered in many aspects, in depend on specific foundry realities in which method is applied.

In case of applied of pig iron in charge this method makes possible partially or even completely it elimination and replacement with steel scrap, what in consequence give:

- reduction of melt cost as a result from price difference of these charge materials,
- use to melt bigger amount of steel scrap which is, in many cases for cast iron foundry, low useful material for low carbon content sake,

In pig iron -less melting process describing method makes possible:

- quick and certain carbon content correction after melt metal charge materials (shortening carburization time and as a results melt time)
- production of different range of cast iron, even nodular cast iron which required higher carbon content, based on process and steel scrap,
- reduction of graphite materials dusting in comparison with traditional methods, because carburizer are injected under the liquid metal surface,
- work facilitation of furnace service, by elimination hand loading of carburizer and it replacing with accurate pneumatic batching. During analyze of process of powdered material injection in carried gas stream may be distinguished in it several elements. Powdered reacting substance, carried gas, batching and control system, transportation system, construction and insert way of the lance, liquid metal properties, and phenomenon occurring during injection of gas-powder mixture to metal batch. Each of them has several characteristic features or properties. In the figure 1 comparison of basic factors characterized process of pneumatic injection powders are presented. This process besides technological and economical dimension has human factor taken into account very rare. It makes possible to decrease of smelters work onerous. Injection of big amount powdered materials in carried gas stream eliminates physical hard work more over application of devices and lance manipulators automation reduce device service to one person.

5.1. Stand of gas-operated carburizing

The main part of the device is a pressure tank 1 (fig. 1) of 3 dm^3 volume. Such volume completely ensures proportioning properly portion of material and makes possible its increase. A bell seal 4 is situated at the upper part of the tank, and a mixing chamber 2 below. On the tank, a venting valve is mounted for pressure relief of the tank after the termination of each working cycle. Pressure of gas supplied to the tank controlled by reducers 6 and 7. A master valves 5 and 9 make possible to supply or cut off the gas supply. The valves (master 5 and 9, bell 4 closure and opening of mixing chamber 2) are started manually. The tank is founded on a strain gauge scale 3, which indications are displayed on the control panel. In its initial position, the balance indicates a mass of material contained in the tank (net). At the moment of starting the haulage cycle, it shows a quantity of material, which has been inserted into liquid metal. Switching off the haulage causes displaying the mass left in the device. It is very comfortable for the operators. A transport pipe 12, terminated in a lance 13 that is introduced into an induction furnace 14, transports carburizer. The diameter of lance was 5 mm. For pneumatic conveying as a carrying gas the argon taking from cylinder 8 was used. In supply installation the filter 10 was applied. Intensity of gas flow was measured with thermal gauge of flow 11.

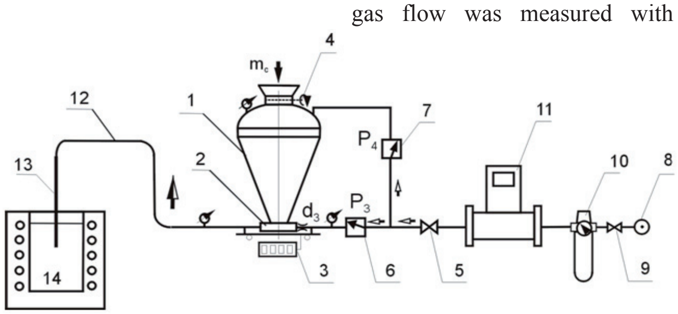

Fig. 1. Scheme of stand for gas-operated metal bath carburising

5.2. Course of carburizing process

After melted metallic charge and reached right temperature (1450^oC), the specimen for chemical analysis was taken. Next the weighted portion of carburizer was poured into the tank of batching device. After opened valves cutting gas supply, lance had been immersed and carburizer was being batched into liquid metal. After inserted whole portion of carburizer first material supply and next gas supply was cut. Right after end of process specimen for chemical analysis was taken. Results of carburising process effectiveness are presented in table 3.

Table 3.
Comparison of results obtained in each melt carburised with pneumatic injection of carburizer to liquid metal

No of melt	Fraction [mm]	m_m [kg]	m [kg]	C_p [%]	C_k [%]	E [%]
5.10	0-1.6	11.4	0.15	0.28	1.31	82.4
5.11	0-1.6	11.4	0.15	1.31	2.33	81.6
5.12	0-1.6	11.4	0.15	2.33	3.31	78.4

In this method effectiveness in range 78 – 82% has been obtained. It may be observed that effectiveness decreasing along with carbon content at the beginning increasing but this fall is insignificant. The follow hypothesis may be given that in case of pneumatic carburization carbon content in metal bath at the beginning has a very weak influence on obtained effectiveness factors. In each tests high and repeatable results have been obtained what have a high importance for industrial practise. Next advantage of this method is very short time of carburising process. Practically right after end of material batching (with well matched parameters of diphase stream), carburizer is solubilized by liquid metal.

Pneumatic injection of carburizer to liquid metal method is modern method of synthetic cast iron production with content of carbon precision controlled. This process required application of batching device and installation for gas supply. Disadvantage is only metal splashing during run of carburizer batching process. It requires furnace cover application and selection proper parameters of diphase stream injection to metal bath.

6. Summary

Carried out experiments of metal bath carburizing in electric induction furnace with three methods show that melted cast iron basis only on steel and process scrap is possible. Analysed carburizing methods make possible to obtain degree of making use of carbon in range 60-91%. It is necessary to, for each method, make selection of carburizer type and parameters of its insertion (in case of pneumatic carburization). Carried out researches in field of quality in this way obtained cast irons (not presented in this work) [4, 5], have shown that properties of synthetic cast iron are not worse that properties of cast iron melted from pig iron. It concerns both gray cast iron and ductile cast iron (on condition that proper quality of steel scrap have been assured). Limitation or elimination of pig iron from charge material causes significant decreases costs of cast iron melt.

Carburizer addition to solid charge makes possible to obtain high effectiveness but not secure right repeatability of process what in consequence caused necessity of carburization with other method.

Addition of carburizer on surface of liquid metal method significantly lengthens melt time and in practice it may be used for replenishing not large carbon deficiency.

Pneumatic injection of carburizer to liquid metal method makes possible to obtain high effectiveness and right repeatability of process in short time. But requires rather significant financial outlay on proportioning devices purchase and secures supply of carrying gas. In Foundry Department of Institute of Engineering Materials and Biomaterials, Silesian University of Technology as well occurred researches of pneumatic injection of solid particles into metal liquid composite matrix as well as pneumatic injection of alloy additions into metal bath.

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