ISSN 1392 - 1207. MECHANIKA. 2005. Nr.5(55)

Quality of synthetic cast iron manufactured in plasma-induction furnace

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1. Introduction

A basis for the classification of grey cast iron, both according to the Polish Standard PN-92/H 83106 and to the standards of other countries, is its minimal tensile strength determined on a sample of diameter d_0=20mm, produced from a separately casted roller of the diameter φ=30 mm and length 300 mm. Although tensile strength provides a basic criterion for cast iron quality, the opinion that the problem of cast iron quality is of more sophisticated character and the problem of cast iron strength σ_u should be considered together with its other features, e.g. hardness, modulus of elasticity E, and impact strength KC, becomes more and more common. W. Patterson and A. Collaud have introduced some following indexes determining the quality of cast iron according to chemical composition: relative hardness HB_w, relative strength $\sigma_{u,w}$, and complex quality index LJ or Q_i. According to chemical composition optimal values of the modulus of elasticity have been defined, characterizing a cast iron of good quality [1,2].

At present crucible induction furnaces are more often applied for cast iron melting. The essential disadvantages of these furnaces is low temperature of slag limiting the course of reaction between the slag and metal. Melt in an induction furnace consist of suitably chosen charge materials remelting and overheating of liquid alloy till required temperature.

As a result of co-operation between The Foundry Laboratory and The Institute of Electrical Engineering (both Poznan Technical University) induction-plasma installation for melting was built.

Plasma, as an additional source of energy in an induction furnace shows the following features:

- does not pollute the liquid metal with undesired impurities;
- provides good stability of electrical parameters, which enable control process and simplifies its course;
- gives high temperature (up to 14000ºC in argon plasma) and energy concentration;
- enables refining and intensifying of melting processes;
- according to the kind of used plasma-generating gas the melt may be effected in any atmosphere.

Laboratory research showed positive influence of induction-plasma melting on mechanical and plastic properties of cast ferrous alloys. An increase of strength was found out especially for impact strength of such cast ferrous alloys as: grey cast iron, carbon cast steel and stainless cast steel [3,4]. The results of this research were confirmed in a foundry in an induction furnace with the capacity of 300 kg. Moreover it was shown that induction-plasma melting increased the efficiency of induction furnace two times with less consumption of electrical energy by about 25 % [5].

Basic raw materials used for grey cast iron manufacturing are foundry irons, ferrous and iron scrap. The cheapest raw material that may be used in production of cast iron is ferrous scrap. The cast iron obtained in the result of steel carbonizing is called synthetic cast iron. The main obstacle to the wide use of ferrous scrape in synthetic cast iron manufacturing is low effectiveness of known methods of iron and steel carburizing.

Research on the kinetics of iron and steel recarburization was the subject of number of papers [6, 7]. It shows that recarburizing of liquid ferroalloys depends on the following factors:

- temperature of the process;
- chemical composition of liquid metal;
- mixing of liquid metal;
- kind of carburizer;
- furnace atmosphere.

There are two main ways of recarburization during steel melting in foundries. Strewing the liquid metal surface with carburizer or blowing any powdered carburizer by means of nitrogen or air fluxes. The first method assures efficiency of the process from 30 to 50 % the second from 50 to 70 % [6].

2. Experiments

The research on obtaining synthetic cast iron in induction-plasma furnace was carried out in Foundry Laboratory by means of installation consisting of induction furnace PI50/8 and plasma torch together with plasma supply and control systems. The scheme of laboratory induction-plasma furnace is presented in Fig. 1.

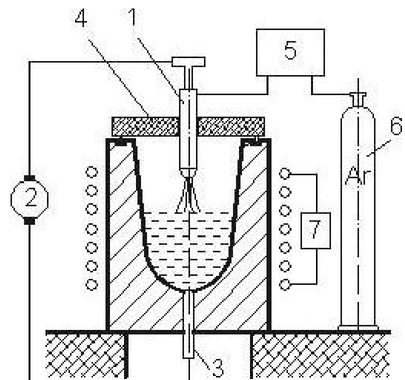

Fig. 1 Outline of the research stand. *1* - plasmatron; *2* - DC-current generator; *3* - bottom electrode; *4* - furnace cover; *5* - rotameter; *6* - argon cylinder; *7* - medium frequency oscillator

Characteristic features of induction furnace:
- maximal crucible capacity - 50 kg
- power of the furnace - 56 kW
- current frequency - 8000 Hz
- furnace lining - quartzite

and DC-current arc plasmatron:
- maximal power - 25 kW
- plasma generating gas - argon

Melting of synthetic gray cast iron in the induction-plasma furnace was followed by the research on efficiency of recarburizing of Armco iron and cast steel. As a charge material Armco iron or steel with chemical composition given in Table 1 was used. Kind and chemical composition of carburizers are presented in Table 2 (carbon and sulphur contents was analysed by means of automatic analyser METALYT CS ELTRA Gmbh).

Table 1

Chemical composition of Armco iron and steel

Chemical composition, %					
C	Si	Mn	P	S	Cr
0.012	0.02	0.015	0.0065	0.086	0.0005
0.21	0.360	0.600	0.014	0.020	0.170

Table 2

Chemical composition of carburizers

Carburizer		Chemical composition, %			
Kind	Marking	Carbon	Sulphur	Ash	Volatile matter
Graphite A	I	96.88	0.136	1.03	1.95
Graphite B	II	94.78	0.556	4.44	0.22
Anthracite A	III	75.85	0.799	15.61	7.74
Anthracite B	IV	88.45	0.853	4.38	6.32

All induction-plasma melts were carried out in a similar way. The furnace was loaded with either Armco iron or steel together with carburizer. During all tests liquid metal was holded for 15 minutes after melting the charge at the temperature 1460-1500ºC and samples were taken to define the final carbon content. Samples for the research on carburization efficiency were put into guartz pipes. Carbon content was determined by means of Leco analyser CS244. Carbon assimilation ratio and carburization efficiency were calculated by means of formulas given under the Table 3.

Samples for mechanical properties testing were casted according to ISO standard 185:1988. The testing machine INSTRON 4260 and hardness tester WOLPERT were used for strength and hardness testing respectively.

Two lots of synthetic grey cast iron melts have been effected. In the 1st lot an unmodified synthetic grey cast iron was produced. Final chemical composition of the cast iron was determined changing the mass of carburizing factor introduced into the furnace with ferrous scrap and the mass of ferroalloys added to the liquid cast iron. The 2nd lot was carried out with inoculation process.

3. Results and discussion

Table 3 shows the results of research on recarburizing efficiency. Table 4 shows the rate of Armco iron recarburization at the temperature 1460-1480ºC. Initial research on the efficiency of Armco iron recarburization in induction-plasma furnace using different carburizing materials allowed to select the most effective carburizer for further research. That was graphite carburizer marked as I in Table 3. The use of different fraction of that carburizer in further research allowed to state its optimal size from the view point of carbon assimilation ratio and efficiency of the process.

Table 3

Results of recarburization of Armco iron (A) and Steel (S)

Carburizer	Mass of charge, kg	Mass of carburizer, kg	$C1$, %	$C2$, %	B, %	E, %	Charge material
I	32	1.4	0.012	3.95	92.9	92.9	A
II	30	1.6	0.012	3.22	63.5	63.5	A
III	30	1.6	0.012	2.71	68.6	68.6	A
IV	30	1.6	0.012	3.26	68.9	68.9	A
I	30	1.4	0.012	4.28	94.5	91.5	A
I	30	1.4	0.012	4.35	96.3	92.9	A
I	30	1.4	0.012	4.27	94.3	91.2	A
I	30	1.2	0.21	3.89	94.9	92.0	S
I	37	1.3	0.21	3.54	97.8	94.8	S
I	30	0.9	0.21	3.05	97.7	94.7	S

$C1$ - initial content of carbon, $C2$ - final content of carbon, B - carbon assimilation ratio, E - efficiency of carburization,

$$B = 100\, m_c \frac{(C2 - C1)}{a m_{cr}} \qquad E = m_c \frac{(C2 - C1)}{m_{cr}}$$

where m_c is mass of charge, kg; m_{cr} is mass of carburizer, kg; a is pure carbon content, %.

Results of recarburizing of Armco iron and steel point at high efficiency of recarburizing in induction-plasma furnace especially for the carburizer marked as I. It should be underlined that about 90% of total carbon content was assimilated during overheating of the liquid metal at the temperature 1460ºC.

Table 4

Recarburizing rate of the liquid Armco iron at the temperature 1460 - 1480°C

Time, min	0	5	10	15	20
Carbon, %	0.012	1.67	2.99	3.12	3.56

Results of the studies of steel carburization in an induction-plasma furnace, using argon as plasma-generating gas, have shown high, exceeding 90%, effectiveness of the process. Carburizer carbon utilization reached even 100% (Table 3). Taking into account current prices of charge materials, i.e. steel scrap, carburizer, and pig iron, the cost of manufacturing 1 ton of synthetic cast iron might be lower by about 40% as compared to the foundry iron [8].

Results of the research give an evidence that without a modification process cast iron having the strength from 150 to 350 MPa may be obtained. Inoculation process allows to produce cast iron of the strength from 300 to 400 MPa.

The research allows to ascertain that synthetic cast iron is characterized by better mechanical properties than the cast iron melted of traditional raw materials. This is confirmed by quality coefficient $LJ > 1$ (according to Patterson) shown in Table 5. The chemical composition of synthetic cast iron is presented in Table 6.

Table 5
Mechanical properties and quality index *LJ* of synthetic cast iron (according to Patterson)

No	σ_u, MPa	*HB*	LJ^*
1	190	219	1.06
2	268	207	1.58
3	293	199	1.38
4	277	208	1.00
5	267	218	1.57
6	366	228	1.06
1M	314	210	1.07
2M	383	232	1.15
3M	330	205	1.15
4M	330	217	1.11
5M	355	220	1.14
6M	453	255	1.25

*) $LJ = \frac{\sigma_{u,rz}}{HB_{rz}} \frac{539-355S_c}{1020-825S_c}$, $S_c = \frac{C}{4.26-0.3(Si+P)}$

where $\sigma_{u,rz}$; HB_{rz} are measured values σ_u and *HB*

Table 6
Chemical composition of synthetic cast iron

No	Chemical composition, %				
	C	Si	Mn	P	S
1	3.79	1.28	0.83	0.030	0.021
2	3.40	1.28	0.83	0.283	0.022
3	3.05	3.25	0.90	0.304	0.020
4	3.05	2.27	0.93	0.045	0.026
5	2.78	4.20	0.94	0.446	0.017
6	2.80	2.45	0.65	0.141	0.023
1M*)	2.63	2.23	0.83	0.020	0.020
2M	2.99	1.68	0.85	0.025	0.031
3M	2.98	1.77	0.60	0.019	0.031
4M	2.80	1.96	0.59	0.023	0.035
5M	2.85	2.08	0.91	0.025	0.029
6M	2.79	2.16	0.62	0.016	0.023

*) inoculated cast-iron

4. Conclusions

The research performed in laboratory with plasma-induction furnace allows to formulate the following conclusions.

1. In plasma-induction furnace all grades of grey cast iron may be manufactured of ferrous scrap.

2. Without inoculation a synthetic grey cast iron of the strength up to 300 MPa may be produced, while inoculation process enables to improve the strength of the cast iron up to 400 MPa.

3. The synthetic cast iron produced in a plasma-induction furnace is distinguished by its improved quality as compared with the cast iron produced of traditional raw materials.

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W. Lybacki

SINTETINIO LIEJAMOJO KETAUS, GAMINAMO PLAZMINĖSE-INDUKCINĖSE KROSNYSE, KOKYBĖ

R e z i u m ė

Straipsnyje pateikiami sintetinio liejamojo ketaus gamybos plazminėse-indukcinėse krosnyse tyrimo rezultatai. Nustatyta, kad plazminis-indukcinis procesas sudaro palankias sąlygas gaminti aukštos kokybės, gerų mechaninių savybių pilkąjį sintetinį ketų.

W. Łybacki

QUALITY OF SYNTHETIC CAST IRON MANUFACTURED IN PLASMA-INDUCTION FURNACE

S u m m a r y

The work presents the results of research of synthetic cast iron production in an plasma-induction furnace. It was ascertained that the plasma-induction process provides advantageous condition for manufacturing of synthetic grey cast iron of high grade and good mechanical properties.

В. Лыбацки

КАЧЕСТВО СИНТЕТИЧЕСКОГО ЧУГУНА, ПРОИЗВОДИМОГО В ПЛАЗМЕННО - ИНДУКЦИОННЫХ ПЕЧАХ

Р е з ю м е

В статье представлены результаты исследования качества синтетического чугуна производимого в плазменных - индукционных печах. Определено, что плазменно - индукционный процесс создал благоприятные условия при производстве серого синтетического чугуна высокого качества с хорошими механическими характеристиками.

Received January 19, 2005