The influence of the technological parameters on the efficiency of the metal melts alloying process by pulverulent material injection

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The alloying of the metal bath represents a usual way in the advanced materials obtaining and refining processes. For this, in the metallic melt are introduced various adding materials, having the role of correcting the chemical composition. A new technology, which allows the precision (micro-) alloying of the metallic melts, is represented by the pulverulent material injection. The aim of the work is to present the experimental results and conclusions regarding the study of the nature and dimension of the pulverulent material particle injected into a non-alloyed metal melt on the alloying efficiency. The experiments were developed under various technological conditions, by variation of the nature and flow rate of the injected gas.

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1. Introduction

The metal melt's refining process by pulverulent material injection was extended in various metallurgical domains as: desulphurization, deoxidization, dephosphorization, the non-metallic inclusion shape and morphology changing, the alloying and micro alloying [1,2,3]. The results of these processes are influenced by the nature and characteristics of the used powders as well as by the injection dynamical parameters [4, 5].

The alloying processes of the metal melts by pulverulent material injection uses as bearer gases Argon and Nitrogen, gases also with important role in the homogenizing (thermal and chemical) and refining of the melt. The development of the technological proceeding imposes the establishment of some technological parameters that characterize the powder particle dynamic regime and the using regime of the fluidization-refining agent.

The influence factors on the metal melts alloying process by powder injection are: the powder nature and flow, the injected particle diameter, the bearer gas nature and flow, the injection pressure, the injection depth and the injection lance characteristics (inner and/or outer diameter) [5, 6, 7].

2. Experimental

The experimental researches for determining the influence of the pulverulent material particle nature and dimension on the metal melt alloying by injection consist in making and treatment of the metal bath with carbonic pulverulent materials: graphite and coke. The physical characteristics of the used carbonic materials are presented in Table 1.

Table 1. The physical characteristics of the carbonic materials used in the experiment.

Materials	Phisical characteristic				
	Humidity W^a, %	Ashes A^{anh}, %	Real density ρ_{real}, kg/m^3	Apparent density ρ_{ap}, kg/m^3	Carbon content C_{fix}, %
Coke	very low	12.43	1732	966	85.9
Graphite	-	max. 0.30	2200	1500	min. 99

For the obtainment of the metal melts which are treated by injection was used a 75 Kg induction furnace which works at the atmospheric pressure.

The carbon powder injection process was made using a injection installation presented in fig.1.

The metal bath making process consist in the melting, into the induction furnace, of a 40 Kg cleans non- alloyed steel scrap. The limitation of the charging weight was made for diminishing the quantity of splashing resulted during the process. After the melting, the metal bath was prepared for the alloying by injection with carbonic

products: graphite and coke. Considering the mentioned aspects, every analyzed charge was deoxidized using the following material alloys FeSi 75 – 3 g/kg steel and respectively Al – 2 g/kg steel.

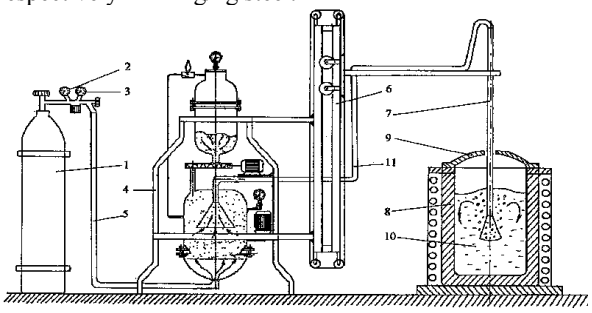

Fig. 1. Experimental device:1 – Argon cylinder; 2 – pressure reducer; 3 - flowmeter; 4 – injection installation; 5 - hose for Argon; 6 – device for manipulating the injection lance; 7 - lance; 8 – induction furnace; 9 - lid; 10 – metal bath; 11 – pipe.

The chemical composition after the melting and the deoxidation of the experimental charges, in which the carbon contend $[C]_o$ represents the beginning value of the alloying by injection process, are presented in Table 2.

Table 2. Chemical composition of the charges.

Charge	Chemical composition of the metal bath, %				
	$[C]_0$	Si	Mn	P	S
I	0.14	0.40	0.25	0.013	0.030
II	0.12	0.37	0.40	0.022	0.027
III	0.12	0.40	0.55	0.020	0.030
IV	0.16	0.28	0.25	0.032	0.032
V	0.10	0.32	0.52	0.017	0.030
VI	0.13	0.27	0.45	0.030	0.038
VII	0.10	0.32	0.64	0.024	0.038
VIII	0.12	0.42	0.55	0.027	0.028
IX	0.16	0.38	0.63	0.018	0.025
X	0.18	0.48	0.63	0.018	0.032
XI	0.14	0.26	0.52	0.025	0.030

After the deoxidation was developed the alloying process by pulverulent material injection using carbonic materials: graphite and coke. The technological parameters imposed for the powder injection into the non-alloyed metal melts were the following:

- The working medium: Argon (Nitrogen) + graphite (coke) powder;
- The working pressure – 2.5 atm;
- The technological mixture injection depth: h_{inj} = 0.15 m;
- The injection lance inner diameter – 10.4 mm;
- The injection lance outer diameter – 15 mm.

The graphite and coke powder injection were performed by variation of some technological parameters (different gas flow rates and two type of gas - Argon and Nitrogen). The powder flow was 350 g/min, for a total quantity of 250 g/charge.

The research methodology has been consist in the injection of 50 g of powder and drawing of the $[C]_1$ and $[C]_2$ samples, and than the injection of 50 g and respectively 100 g of pulverulent material and drawing of the $[C]_3$ and $[C]_4$ samples, for the carbon content determination of its. Between the $[C]_2$ and $[C]_3$ samples the metal bath was reheated by connecting the furnace to the power for 5 min, because by injection of the pulverulent material the metal bath was cooling rapidly.

3. Results and discussions

The results of the experimental researches have been grouped in two sets depending on the characteristic parameters. They are presented in tables 3 and 4.

The chemical composition of the metal bath has been determined in order to study the carbon content evolution. The carbon theoretical and practical values and the assimilation degree after each injection operation are presented in tables 5 and 6. The efficiency of the metal bath alloying process with carbon pulverulent materials, η_C was calculated using eq. (1) and (2):

$$\eta_C = \frac{[C]_{asim}}{[C]_{th}} \cdot 100\,,\ \%, \tag{1}$$

or:

$$\eta_C = \frac{[C]_f - [C]_i}{[C]_{th} - [C]_i} \cdot 100\,,\ \%, \tag{2}$$

where: $[C]_{asim}$ represents the assimilated carbon quantity in the metal bath;
- $[C]_f$ - the final carbon content of the metal bath;
- $[C]_i$ - the initial carbon content;
- $[C]_{th}$ - the theoretical carbon content assimilated in the metal bath.

Table 3. First set of results.

Experiment	Powder	Injection gas	Gas flow rate, m^3_N/h	Particle diameter, mm	Working pressure, atm	Injection depth, m	Lance inner diameter, mm
I	Graphite	Argon	0.00094	max. 0.4	2.5	0.15	10.4
II	Graphite	Argon	0.00094	max. 0.5			
III	Graphite	Argon	0.00133	max. 0.4			
IV	Graphite	Argon	0.00133	max. 0.5			
V	Coke	Argon	0.00094	max. 0.4			
VI	Coke	Argon	0.00133	max. 0.5			

Table 4. Second set of results.

Experiment	Powder	Injection gas	Gas flow rate, m^3_N/h	Particle diameter, mm	Working pressure, atm	Injection depth, m	Lance inner diameter, mm
VII	Graphite	Nitrogen	0.00094	max. 0.4	2.5	0.15	10.4
VIII	Graphite	Nitrogen	0.00094	max. 0.5			
IX	Graphite	Nitrogen	0.00133	max. 0.5			
X	Coke	Nitrogen	0.00094	max. 0.4			
XI	Coke	Nitrogen	0.00133	max. 0.5			

Table 5. The evolution of the carbon content for the first set of experiments.

Experiment			Sample				
			$[C]_0$	$[C]_1$	$[C]_2$	$[C]_3$	$[C]_4$
Carbon content, %	I	practical	0.14	0.20	0.26	0.31	0.48
		theoretical	-	0.26	0.39	0.51	0.76
	II	practical	0.12	0.20	0.25	0.36	0.49
		theoretical	-	0.24	0.37	0.49	0.74
	III	practical	0.12	0.18	0.32	0.42	0.54
		theoretical	-	0.24	0.37	0.49	0.74
	IV	practical	0.16	0.27	0.35	0.49	0.61
		theoretical	-	0.28	0.41	0.53	0.78
	V	practical	0.10	0.17	0.19	0.25	0.38
		theoretical	-	0.21	0.31	0.42	0.63
	VI	practical	0.13	0.22	0.25	0.31	0.43
		theoretical	-	0.25	0.34	0.45	0.67
Quantity of injected powder, g			-	50	100	150	250
Specific powder consumption, kg/t			-	1.25	2.50	3.75	6.25
Assimilation efficiency of carbon, %	I		-	50.00	48.00	45.95	54.84
	II		-	66.66	52.00	64.86	59.68
	III		-	50.00	80.00	68.86	67.74
	IV		-	91.66	80.00	89.18	72.58
	V		-	63.63	42.85	46.87	52.83
	VI		-	75.00	57.14	46.87	55.55

Table 6. The evolution of the carbon content for the second set of experiments.

Experiment			Sample				
			$[C]_0$	$[C]_1$	$[C]_2$	$[C]_3$	$[C]_4$
Carbon content, %	VII	practical	0.10	0.19	0.26	0.35	0.38
		theoretical		0.22	0.35	0.47	0.72
	VIII	practical	0.12	0.17	0.27	0.38	0.50
		theoretical		0.24	0.37	0.49	0.74
	IX	practical	0.16	0.25	0.32	0.42	0.60
		theoretical		0.28	0.41	0.53	0.78
	X	practical	0.18	0.24	0.28	0.33	0.46
		theoretical		0.28	0.39	0.50	0.72
	XI	practical	0.14	0.21	0.27	0.38	0.42
		theoretical		0.24	0.35	0.46	0.67
Quantity of injected powder, g			-	50	100	150	250
Specific powder consumption, kg/t			-	1.25	2.50	3.75	6.25
Assimilation efficiency of carbon, %	VII		-	75.00	64.00	67.56	52.34
	VIII		-	41.66	60.00	70.27	61.29
	IX		-	75.00	47.62	70.27	70.96
	X		-	60.00	47.62	46.87	51.85
	XI		-	70.00	61.90	75.00	52.83

Based on the experimental values from tables 3 – 6, were plotted simple correlation diagrams between some parameters of the technogical process. These diagrams show the influence of the pulverulent material particles' nature and dimension on the carbon assimilation degree in the metal melts:

- The variation of the carbon assimilation degree with the Argon flow rate and the maximum diameter of the injected particle (fig. 2);

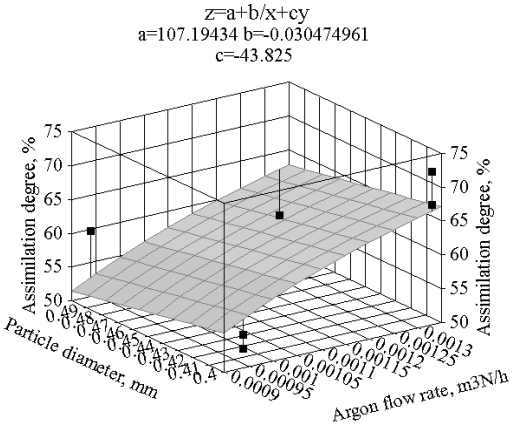

Fig. 2. The variation of the carbon assimilation degree with the Argon flow rate and the maximum diameter of the injected particles.

- The variation of the carbon assimilation degree with the Nitrogen flow rate and the maximum diameter of the injected particle (fig. 3);

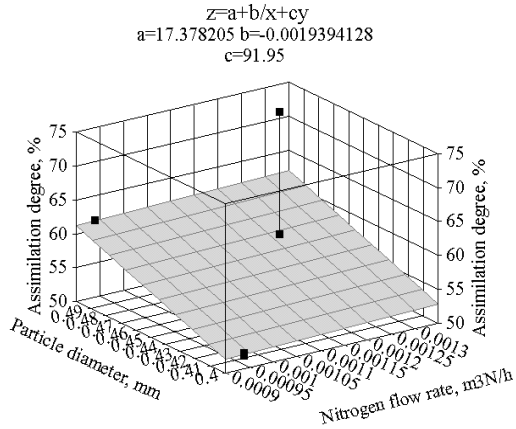

Fig. 3. The variation of the carbon assimilation degree with the Nitrogen flow rate and the maximum diameter of the injected particles.

- The variation of the carbon assimilation degree with the gas flow rate and the graphite particle diameter (fig. 4);
- The variation of the carbon assimilation degree with the gas flow rate and the coke particle diameter (fig. 5).

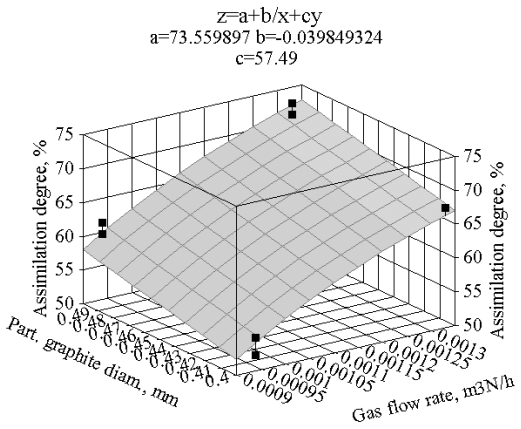

Fig. 4. The variation of the carbon assimilation degree with the gas flow rate and the diameterof the graphite particle.

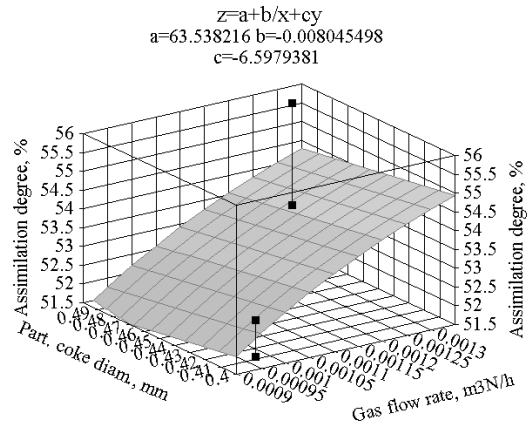

Fig. 5. The variation of the carbon assimilation degree with the gas flow rate and the diameter of the coke particle.

Based on the data from tables 3 – 6 and correlation diagrams from fig. 2 – 5 the following are observed:

- The dispersion degree of the results obtained at coke and graphite injection inside the metal bath is very large, between 52.34 % and 72.58 %. This fact is due to the different development conditions of the experiments.

The best results have been obtained by a better combining of the process injection parameters with the pulverulent material properties (experiment number IV);

- The gas nature has no important influence in the development of the technological process. The carbon assimilation efficiencies have similar results for both Argon injection and Nitrogen injection, when the other technological parameters are similar. The maximum values are 72.58 % for Argon (exp. IV) and 70.96 % for Nitrogen (exp. IX);
- The gas flow rate is very important for the carbon assimilation efficiencies. The maximum values of the

carbon content are obtained by increasing the gas flow rate from 0.00094 m^3_N/h to 0.00133 m^3_N/h;

- The injected quantity of the pulverulent material depends on the carbon content of the metal bath in all 11 experiments;
- The quality of the pulverulent material has a great influence on the dissolution process. The carbon content values are lower in the case of coke injection, compared to graphite injection, due to a lower reaction power and the C_{fix} content;
- The dimension of the injected particles plays an important role on the metallurgical processes efficiency. During the experimental researches have been chosen particles from two-dimensional classes: 0 – 0.4 mm and 0 – 0.5 mm. For the first class (0 – 0.4 mm), the increase of the gas flow rate from 0.00094 m^3_N/h to 0.00133 m^3_N/h determines the increase of the carbon assimilation efficiency for both graphite (from 52.34 % - exp. VII to 67.74 % - exp. III) and coke (from 51.85% to 55.55 % - exp. V and X). For the second class (0 – 0.5 mm), the increase of the gas flow rate from 0.00094 m^3_N/h to 0.00133 m^3_N/h determines the increase of the carbon assimilation efficiency for both graphite (from 59.68 % % - exp. II to 72.58 % - exp. IV) and coke (from 55.85 % - exp. VI to 52.83 % - exp. XI). The large domain of values for the dimensional classes used determines variable values for the metallurgical efficiency.

These results impose the necessity to choose an adequate particle dimension depending on the hydrodynamics parameters of the metallurgical process [5, 8].

4. Conclusions

The experimental researches show the fact that the alloying process of the metal melts by pulverulent material injection is very efficient, easy to obtain technically, with high carbon assimilation degree, imposed by the technological conditions of the metallurgical process.

The large domain of metallurgical values is due to different development conditions of the experiments, especially because of the gas flow rate and the nature and size of particles which creates distinct particularities for the mentioned process..

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