VERIFICATION OF THE THEORETICAL CONSIDERATIONS AND NUMERICAL MODELING OF THE POWDER INJECTION PROCESS IN CONDITIONS OF PNEUMATIC INJECTION OF FERROALLOYS INTO LIQUID CAST IRON

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Abstract

The problem of pneumatic powder injection into liquid alloys has been analyzed by authors in previous theoretical, model and numerical experiments what was reported in previous articles. Here an issue of semi-industrial hot experiments has been presented. The grey cast iron was melted in laboratory electric induction crucible furnace and then powdered ferrosilicon was pneumatically introduced into liquid bath. A method with lance not submerged in liquid was analyzed as better way in cases when less temperature decrease and less carrier gas introduction into molten metal is desirable e.g. for small metal volumes treatment. The results for various process parameters (carrier gas pressure, diphase jet concentration, ferroalloy grains parameters etc.) have been presented and compared with these obtained by the way of theoretical and numerical considerations. Both the typical steel lance and lance of new design (reported in earlier works) have been verified in semi-industrial conditions. The possibility of successful powder introduction as well as some hypotheses and mathematical assumptions have been proven during the researches. The practical guides how to perform properly the pneumatic powder injection process with non-submerged lance with good efficiency and other parameters have been presented, too. These results finish the wide (four years) experimental plan of development in pneumatic powder injection process to make it ready to wider industrial usage.

Keywords: cast iron, pneumatic powder injection, injection lance, alloy addition, diphase jet

1. INTRODUCTION

The pneumatic powder injection for introducing various powdered materials into liquid metal or alloy is nowadays undisputed method utilized in many metallurgical processes what was described among the others in [1-4]. To make the introduction process easier and more efficient, the grainy material which properties are often crucial [5] is introduced directly under the molten metal surface what was proven by authors in [6-8]. Saying shortly, two methods of powder injection are employed - with and without the injection lance submersion under the surface of the molten metal being treated. Both have the advantages and disadvantages and the one which is most interesting for the authors at the moment is non-submerged lance method [9-10]. The main features of this method were widely described in some previously published articles with these reported during previous Metal conferences, too [11-13]. These articles presented the partial results of theoretical and numerical considerations as well as some model experiment to validate the developed mathematical models [14]. Then the model cold experiments were performed and described thoroughly in [8,14]. This paper presents the final evaluation of the results obtained by the way of semi-industrial pneumatic powder injection of ferroalloys into molten cast iron with use normal lance and lance with a flange invented and patented [15] by authors.

2. EXPERIMENTAL METHODOLOGY AND RESULTS

2.1 Research stand and methodology

The research carried out previously and mentioned in the introduction resulted in the fully theoretically and numerically developed set of parameters of the powder injection which then were tested during the injection of ferro-silicon FeSi75 into molten cast iron in laboratory electric induction furnace. The solid charge was composed of cast iron returns of low silicon content to ensure optimum conditions of its assimilation from ferroalloys after injection. The research stand was similar to this presented in previous publications [2,9,11,13] and the only modification was high speed camera used to record the ferroalloy grains introduction process into molten metal. The pneumatic parameters of the injection installation and the other important process parameters for the normal injection lance were presented in **Table 1** and analogical data are presented in **Table 2** for case of lance with a flange. In each melt the same portion 0,1kg of FeSi75 was injected, the inner lance diameter was 7,6mm and length 1m, compressed air was a carrier gas and the powdered ferroalloy granulation was 0,8-1mm. The lance outlet was situated 60mm above the liquid metal surface because this value seemed to be the best on the base of previous experiments.

Table 1 The main injection process parameters for normal lance

No.	p_1 [MPa]	p_4 [MPa]	t [s]	V_g [m^3/s]	μ [kg/kg]	w_g [m/s]	E [%]	T_p [ºC]	T_k [ºC]
1	0,1	0,02	12,05	0,0009	6,8	22,58	19,72	1448	1457
2	0,2	0,04	9,21	0,0015	5,6	35,65	85,88	1456	1447
3	0,3	0,04	10,23	0,0020	3,8	46,74	86,94	1448	1470
4	0,1	0,08	9,11	0,0028	3,1	66,15	93,72	1450	1500
5	0,2	0,08	4,82	0,0034	4,7	80,41	97,60	1445	1483
6	0,3	0,10	4,53	0,0041	4,1	97,84	88,17	1463	1460

Table 2 The main injection process parameters for lance with a flange

No.	p_1 [MPa]	p_4 [MPa]	t [s]	V_g [m^3/s]	μ [kg/kg]	w_g [m/s]	E [%]	T_p [ºC]	T_k [ºC]
K1	0,1	0,02	12,07	0,0018	3,6	42,76	54,90	1440	1488
K2	0,2	0,04	15,22	0,0022	2,3	52,27	44,15	1471	1501
K3	0,3	0,04	7,12	0,0022	4,8	53,45	34,84	1441	1462
K4	0,1	0,08	3,69	0,0024	8,8	56,62	77,18	1463	1444
K5	0,2	0,08	5,01	0,0027	5,6	64,94	32,64	1444	1447
K6	0,3	0,10	6,37	0,0031	3,9	74,04	54,12	1430	1471
K7	0,2	0,12	2,98	0,0032	8,1	76,42	63,86	1449	1459
K8	0,2	0,14	3,21	0,0029	8,3	68,90	88,86	1452	1457

The captions in the tables are as follows: p_1 - carrier gas pressure, p_4 - gas pressure in the pneumatic feeder above the loaded powdered material, t - injection duration time, V_g - volumetric carrier gas flow, μ - diphase jet concentration (material/gas ratio), w_g - carrier gas velocity on the lance outlet, E - efficiency of the process (silicon assimilation rate), T_p - metal bath temperature before injection, T_k - metal bath temperature after injection.

The injection tests were performed similarly in both cases but because of some pressure loss (it is a result of lance construction described in [15]) two more tests for new lance were ordered. In these injections higher pressure in the feeder p_4 was adjusted to make the concentration μ higher and the jet more penetrating the liquid.

2.2 Results of the experiments

During the laboratory melts the chemical composition of the cast iron was analyzed and the results are presented in the **Table 3** and 4 where '0' in mark in the first column means the initial iron composition then two following injection performed into the same melt in the furnace.

Table 3 Chemical composition of the cast iron during normal lance injection

No.	C [%]	Si [%]	Mn [%]	P [%]	S [%]	Cr [%]	Cu [%]	Ni [%]	Al [%]	Ti [%]
01	2,88	1,10	0,411	0,037	0,012	0,047	0,134	0,045	0,006	0,009
1	2,82	1,21	0,431	0,036	0,012	0,049	0,132	0,041	0,005	0,009
2	2,62	1,70	0,441	0,033	0,012	0,051	0,135	0,042	0,005	0,008
02	2,54	0,84	0,438	0,031	0,009	0,041	0,120	0,038	0,004	0,006
3	2,46	1,32	0,444	0,029	0,009	0,042	0,121	0,038	0,006	0,006
4	2,43	1,90	0,435	0,031	0,011	0,043	0,121	0,039	0,006	0,008
03	3,02	1,17	0,428	0,037	0,013	0,040	0,112	0,036	0,004	0,011
5	2,90	1,69	0,419	0,037	0,014	0,041	0,110	0,037	0,006	0,011
6	2,86	2,17	0,441	0,037	0,013	0,042	0,111	0,035	0,006	0,010

Table 4 Chemical composition of the cast iron during normal lance injection

Nr próbki	C [%]	Si [%]	Mn [%]	P [%]	S [%]	Cr [%]	Cu [%]	Ni [%]	Al [%]	Ti [%]
K01	3,04	1,23	0,414	0,042	0,013	0,045	0,125	0,034	0,004	0,012
K1	2,98	1,52	0,388	0,040	0,014	0,045	0,128	0,039	0,005	0,011
K2	2,98	1,76	0,412	0,042	0,015	0,046	0,125	0,036	0,004	0,010
K02	3,26	1,21	0,394	0,043	0,014	0,036	0,102	0,031	0,003	0,011
K3	2,84	1,38	0,451	0,037	0,013	0,038	0,109	0,035	0,004	0,007
K4	2,86	1,67	0,455	0,039	0,014	0,040	0,108	0,034	0,003	0,008
K03	3,20	1,24	0,406	0,041	0,015	0,039	0,103	0,025	0,003	0,011
K5	2,96	1,42	0,452	0,039	0,014	0,040	0,102	0,026	0,004	0,010
K6	2,90	1,83	0,447	0,037	0,013	0,040	0,103	0,028	0,005	0,011
K04	2,89	1,15	0,303	0,039	0,012	0,039	0,125	0,037	0,002	0,010
K7	2,76	1,95	0,312	0,038	0,012	0,040	0,124	0,037	0,004	0,011
K8	2,83	1,61	0,308	0,039	0,012	0,039	0,124	0,036	0,004	0,010

The pictures and description of the results with use of the normal lance were presented in [16] so here the only these with lance with a flange were described. In the **Fig. 1** the set of photographs for improperly adjusted pneumatic parameters (from *a* to *c*) and the best pneumatic conditions (from *d* to *f*) were shown.

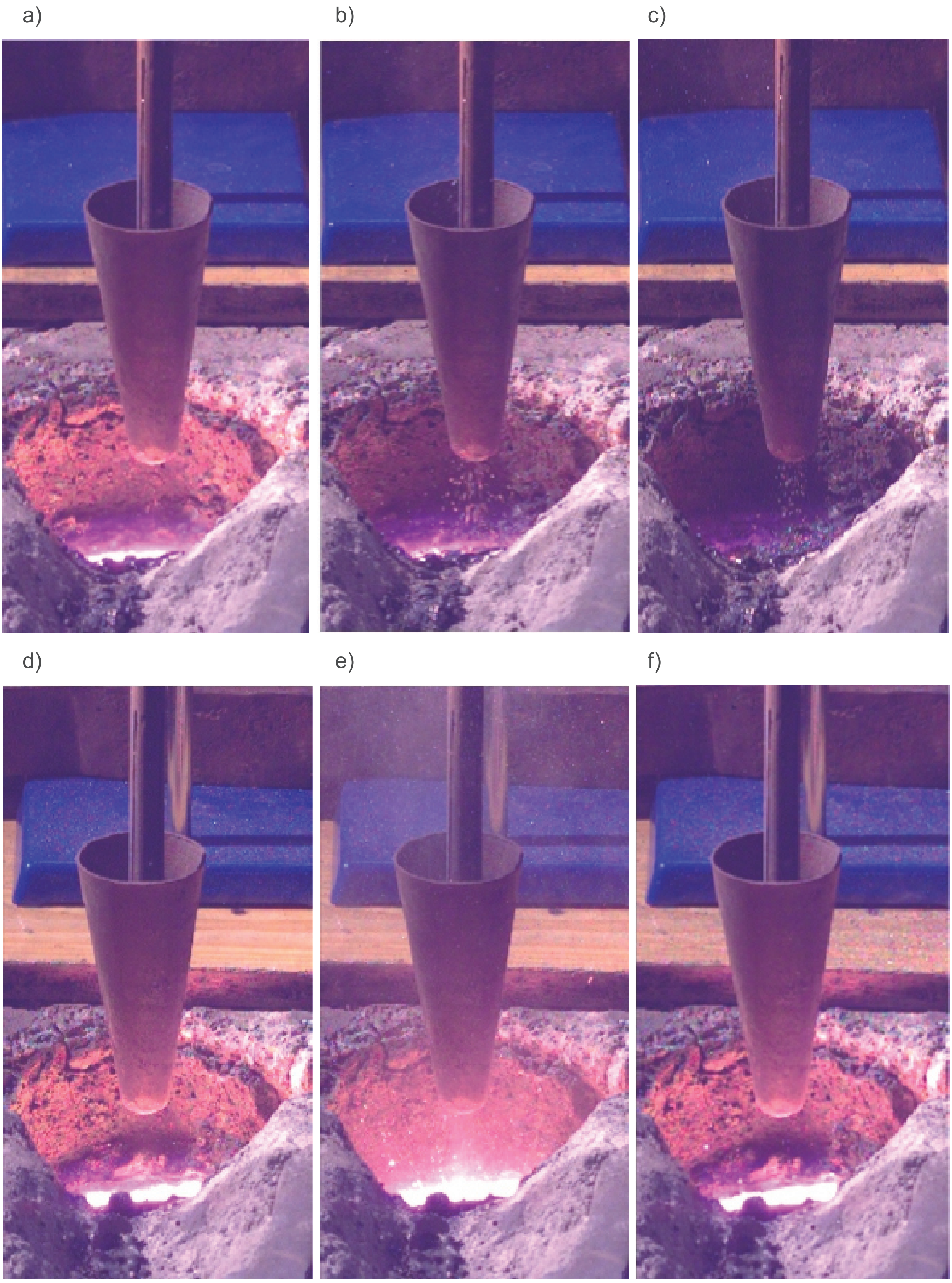

Fig. 1 The comparison of the injection run for two sets of wrong (*a* - *c*) and good (*d* - *f*) pneumatic parameters; following photographs show time = 0, 2 and 6s (the end of injection

It is visible (**Fig. 1** ***a, b*** and ***c***) in the pictures showing the moment of powder injection that when the jet does not possess good dynamics (to less concentration and velocity as a result of wrong pressure adjustment) the penetration into liquid does not occur. The grainy material collects on the liquid surface and the efficiency is unacceptable - see K1 test in **Table 2**. On the second hand when the pneumatic parameters are well-adjusted and the diphase-jet has good dynamics the final efficiency is really good - see test K8 in **Table 2** and **Fig. 1** ***d***, ***e*** and ***f***. As it can be compared in the tables the efficiency of the lance with a flange is slightly lower than for typical lance but it is still very good. Taking into consideration the benefits (lower temperature drop and less gas introduced into molten metal) against the typical lance, the lance with a flange can be used for the treatment of small or medium alloys volume e.g. for inoculation or microalloying.

CONCLUSIONS

The paper presents the final semi-industrial evaluation of the model and numerical studies on the subject of pneumatic powder injection with use of non-submerged lance. Summing up the experiments comparing two types of injection lances it can be stated that:

a) Decisive influence of the mass concentration of the diphase powder-gas jet on the jet penetration into molten metal was proven. It is necessary to achieve high process efficiency thanks to proper pressure in the installation resulting high enough jet velocity on the lance outlet,

b) The research shows that the lance outlet distance from the liquid metal surface can be even eight times more than its inner diameter, when the pressure values p_1 and p_4 are adjusted properly,

c) Well-adjusted injection parameters result in stable and uniform jet penetration into liquid bath, without the splashes and huge gas volume introduced along with the powdered material. Such situation is better because of less temperature drop,

d) The so-called flange lance ensures very good technological process factors as well as a smaller molten metal temperature decrease and smaller carrier gas volume that is introduced into the liquid.

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