SOLID PARTICLE PENETRATION INTO LIQUID ALLOY – AN IMPORTANT ISSUE IN METALLURGICAL PROCESSES

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Abstract

Many metallurgical processes in some moment needs that the specific material in form of chunks, grains, powder, dust etc. must be added. The results and benefits from it depends on the fast and uniform distribution of the introduced material inside the whole volume of the alloy being processed. That is why the method of pneumatic powder injection is widely used to introduce the powdered material of various kinds into the molten alloys. But the problem of particles penetration into the liquid metal is quite complicated and many variables and parameters influence the final result. In the paper the results of the model laboratory research on this problem were presented. The model particles of spherical shape of different dimensions, made of various materials were introduced into water. The geometrical features of the area of particle, entrapped air and water interaction was analyzed. The results were compared to those achieved by other researchers. The results can be then an initial stage to the next research to combine the obtained data with the results of real pneumatic powder injection experiments.

Keywords: cast iron, pneumatic powder injection, particle immersion, particle penetration, penetration dynamics

1. INTRODUCTION

The desired properties of the castings made of various alloys can be obtained by use of different methods and technological approaches [1-6]. The process of the pneumatic powder injection into liquid is based on the huge amount of grains inside the carrier gas jet and authors have been making the research in that field since many years [7-10]. It was years ago when researchers found out that with the solid particles a huge volume of the carrier gas as well as entrapped air was finally introduced into liquid [11-15]. Moreover, all the other processes when solid materials are introduced into liquid alloy generate the same problem and the final alloy obtained may be contaminated with huge volume of gases [16]. The authors presented several research article during the previous Metal series conferences [8-10] where they described both the method of powder injection with and without the injection lance immersion into liquid alloy. The experiments based among the others on the experiments with the jet recording with the high speed camera were presented in [17-19]. The results shown that the excessive gas volume introduced into liquid alloy can lower the overall temperature and the mechanical properties of the produced alloy [16]. That is why the authors launched another experimental plan to try to better understand the problem of solid particles introduction into liquid from the entrapped gas point of view.

2. EXPERIMENTAL METHODOLOGY AND RESULTS

The research stand was designed and assembled to capture the motion of the selected solid spheroidal particles of different properties into model (water) environment. The scheme of the setup is shown in Figure 1 and its main part was the high speed camera connected to the computer equipped with the image analysis software TEMA. The experiments were performed with the use of two materials: rubber and polypropylene of various diameters which were freely thrown from various heights to simulate the conditions of the powder injection with various parameters resulting in various diphase solid-gas jet dynamics. The Table 1 presents the parameters of the selected small balls simulating the round particles and the conditions of the experiments. There were 135 experiments done together and all of them were captured with high speed camera.

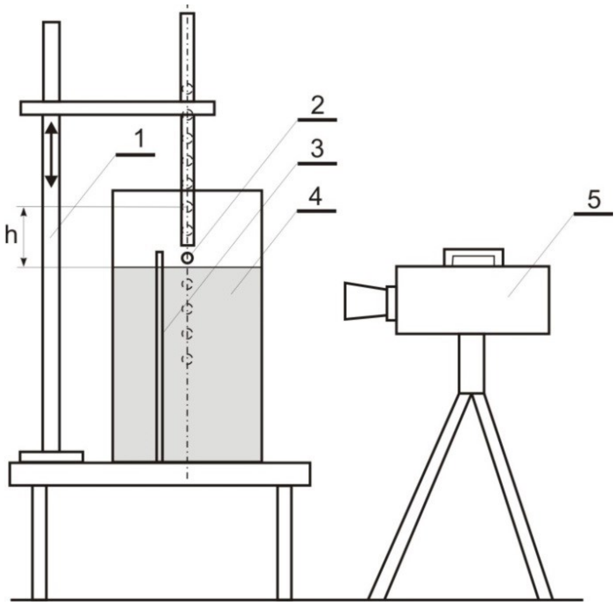

Fig. 1. The research stand for solid particles penetration measure inside liquid medium: 1- rack to desired height set, 2- small ball (model particle), 3- background with measuring grid, 4- model liquid (water), 5- high speed camera [16]

Table 1. The experimental data

Material	Ball diameter, [mm]	Throw height O, [mm]
Rubber	4	120
		220
		320
	15	120
		220
		320
	20	120
		220
		320
Polypropylene	4	120
		220
		320
	15	120
		220
		320
	20	120
		220
		320

After the capturing experiments were finished the image analysis work was done based on the idea described in [12-14] which is shown in Figure 2. The scheme presents the process of the particle of low wettability with the characteristic feature of the gas bubble and some amount of it entrapped on the particle surface which is introduced deeply inside the water. In the real conditions of liquid alloy more dense than water it can be entrapped for long time resulting the temperature decrease and gas porosity. The experiments described here are the first stage model research to try to check the assumptions made earlier in [12-14] and to combine the properties of solid particles with the potential of air and carrier gas entrapment during the powder injection into liquid.

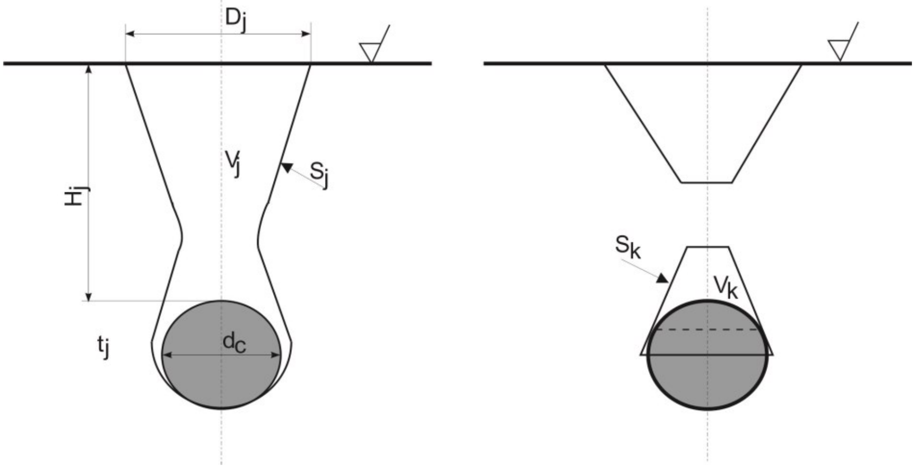

Fig. 2. The scheme of the gas entrapment process with the spheroidal particle of low wettability [16]

The characteristic parameters of the process are:

- Hj – the maximum depth of the gas cavity,
- T_j – the time necessary to reach by the particle the maximum depth,
- D_j – the top cavity diameter,
- S_j – the surface of the air cavity
- V_j – the volume of the gas cavity

The parameters are described by formulas presented in [16] and during the experiments were calculated using the captured motion pictures. The Figure 3 presents the typical feature of the rubber ball introduced into water with high dynamics while the Figure 4 presents the same process for the polypropylene ball.

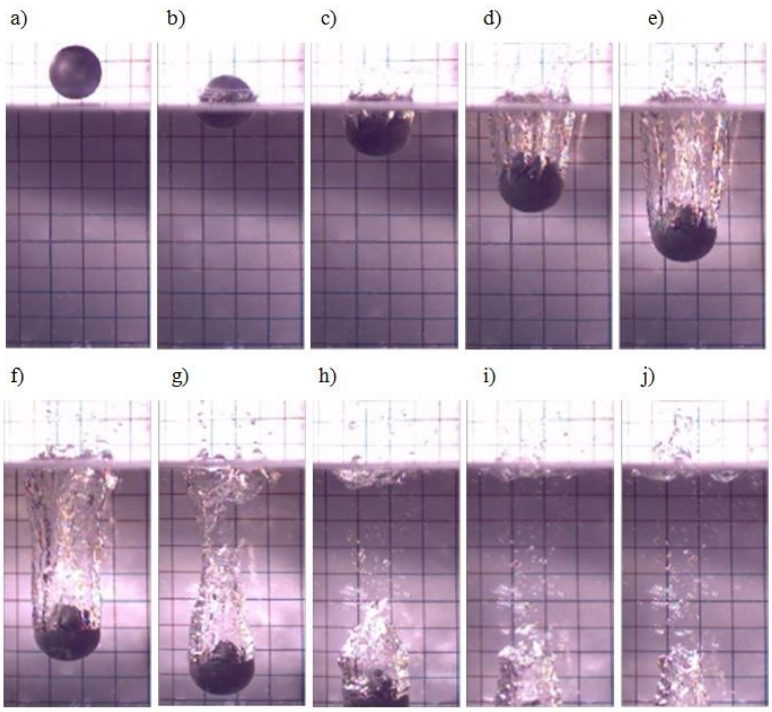

Fig. 3. Rubber ball of 20mm diameter penetration into liquid; throw height 320mm a) t=0, b) t=0.005s, c) t=0.01s, d) t=0.02s, e) t=0.03s, f) t=0.04s, g) t=0.05s, h) t=0.06s, i) t=0.07s, j) t=0.08s

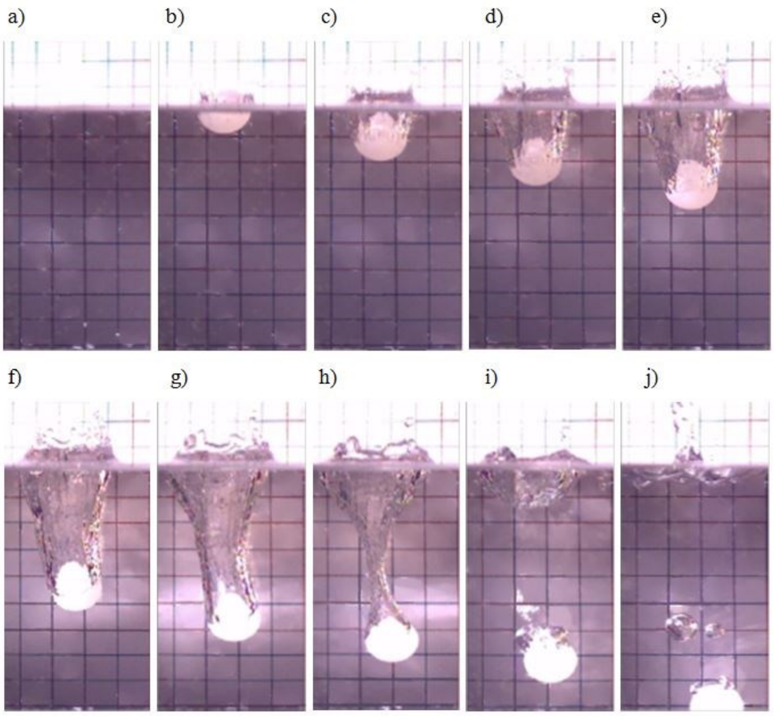

Fig. 4. Polypropylene ball of 15mm diameter penetration into liquid; throw height 320mm a) t=0, b) t=0.005s, c) t=0.01s, d) t=0.015s, e) t=0.02s, f) t=0.03s, g) t=0.04s, h) t=0.05s, i) t=0.06s, j) t=0.09s

The process of penetration shown in Fig. 3 and 4 represents the situation with the low-wettability particles introduced into liquid with the high motion velocity (high jet dynamics). In that case a huge amount of air can be entrapped on the particle surface and introduce deeply into liquid medium. The situation corresponds with the graphic description in Fig. 2 and mathematical formulas presented in [12-14] so the parameters mentioned earlier were calculated and shown in Table 2 together with the other case for the polypropylene ball.

Table 1. The geometrical features of the air cavity for both materials

Material	D_j [m]	O [m]	H_j [m]		T_j [s]		D_j [m]		S_j [m^2]		V_j [m^3] 10^{-5}	
			cal.	meas.	cal.	meas.	cal.	meas.	cal.	meas.	cal.	meas.
Rubber	0.02	0.32	0.092	0.075	0.061	0.051	0.052	0.042	0.007	0.004	4.62	2.41
Polypropylene	0.015	0.32	0.102	0.085	0.054	0.049	0.071	0.050	0.010	0.006	9.27	3.87

It is visible that the values calculated with the formulas taken from [16] (marked 'cal.') differ quite significantly from those measured with use of real captured images (marked 'meas.'). It corresponds with the observations described by authors in [12-15] that the formulas are not so precise for all the materials and depend significantly on their wettability. It is obvious that the powder injection process into liquid alloy is much more complicated from the gas entrapment point of view because there are thousands of particles of various shapes (not always uniform) which introduce the liquid as a 'bulky' jet but the behaviour of single particle in such conditions is still important.

Another situation happens when the velocity of the introduced ball is low. Thus the air is not entrapped on the solid surface and does not penetrate the liquid. It is visible for the rubber ball in the Fig. 5. Such the conditions are better from the gas penetration point of view but the particles velocity can be too low to make the particles jet (in real pneumatic injection) strong enough to penetrate the whole volume being processed.

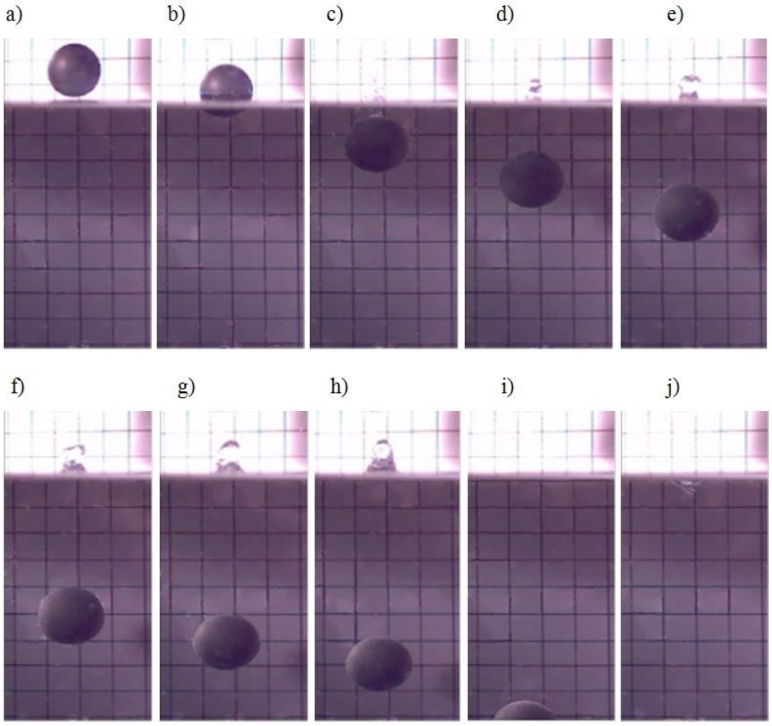

Fig. 5. Rubber ball of 15mm diameter penetration into liquid; throw height 120mm a) t=0, b) t=0.005s, c) t=0.02s, d) t=0.03s, e) t=0.04s, f) t=0.05s, g) t=0.06s, h) t=0.07s, i) t=0.11s, j) t=0.125s

From the gas entrapped point of view the situation shown in Fig. 5 is better than that visible in Fig. 3 and 4 but in such conditions the dynamics of the jet is too low to make the jet enough strong to penetrate the liquid. So the compromise must be obtained between the powder injection process parameters high enough to distribute the particles inside the liquid and low enough to entrapped as low volume of air as possible.

3. CONCLUSIONS

The paper presents the preliminary stage of the research plan to check the possibility of gas (air) entrapment proces by the solid round particles during the pneumatic powder injection process. After the experiments the following conclusions have been drawn:

- The gas entrapment phenomenon is significant for the high velocity of the particles while for the low velocity is often invisible at all,
- The wettability being the result of the material and its surface finish is one of the decisive parameters on the possibility to entrap the air and to transport it under the liquid surface,
- The variables and formulas proposed in [12-14] after the former experiments with use of less quality research equipment seems to be not accurate for solid particles properties other than these used in mentioned research,
- The next step of the research should be an attempt to computer modeling of the process of several particles (as many as possible) to check how the gas entrapment phenomenon will be in the case of combine interaction between them.

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