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BUBBLE FORMATION IN THE WALL OF IRON MICRO-SPHERES

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Abstract
The paper presents mechanisms for bubbles formation in the wall of iron micro-spheres. The gasses diffusion velocity and the bubbles ascension in the melt are high lower in comparison with the iron solidification velocity. Pores are formed, they being influenced by the molar concentration of the gas in the melt.
Keywords: Iron micro-spheres, Pores, Plasma Jet, Gas bubble, Thermal balance.

1. Introduction

The carbon steel semi-finished parts introduced in the argon plasma jet, with pre-established velocities [1,2], are brought to vapor stage. In vapors of small molar concentrations, as compared to the molar density of the mixture, spherical gas-vapors entities are formed [1,4]. The sphere-gas interface changes into a liquid diaphragm when reaching points having temperatures close to dew point. The temperature of the mixture inside the diaphragm is a higher then diaphragm temperature. Following temperature gradient, vapor volume elements move towards diaphragm. When the diaphragm is reached at, there takes place a mass transfer [3,4] through diffusion, under non-steady duty. The process ends at the same time with the micro-sphere liquid wall formation.

The solidified wall of the micro-spheres (Fig.1) is penetrated by pores at ambient temperature. The pores dimensional distribution in the micro-spheres wall is shown in Fig.2. The pores dimensions range between 1 μm and 3 μm, with 39% relative frequency, and between 4.5 μm and 20.5 μm, with 31% relative frequency (Fig.2.a). But, other micro-spheres pores diameter (Fig.2.b) ranges between 3 μm and 26.5 μm (pores associations), of maximum relative frequency. The pores presence makes easier the fluids and nanoparticles penetration in micro-spheres. Consequently, they can be useful at certain substances batching [5,6] and at producing suspensions for bio-medical applications [7,8], etc. Micro-spheres production by the vaporization of carbon steel semi-finished parts in plasma is of high productivity [1,2].

But, the production of micro-spheres with pores in plasma jet is rather difficult, because the process of their obtaining requires the control of several technological parameters. Consequently, we will present below certain mechanisms that take place at the pores formation in iron micro-spheres produced through plasma procedures.

Bubbles formation. Bubbles critical radius.

Gases form bubbles in "condensation centers" in the micro-sphere walls. If they have spherical form, they are energetically stable [9] and the radius of spheres is equal to or greater than the critical radius. According to Kelvin-Thomson model, the bubbles critical radius is:

$$r_c = \frac{2\sigma V_0}{RT \ln S} \qquad (1)$$

where σ is the melt-gas inter-phase tension, V_0 is the gases molecular volume, T is the temperature and S is the super-saturation degree with melt gases.

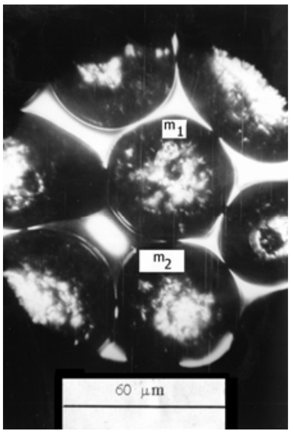

Fig. 1 [1] Field of iron micro-spheres with walls penetrated by pores.

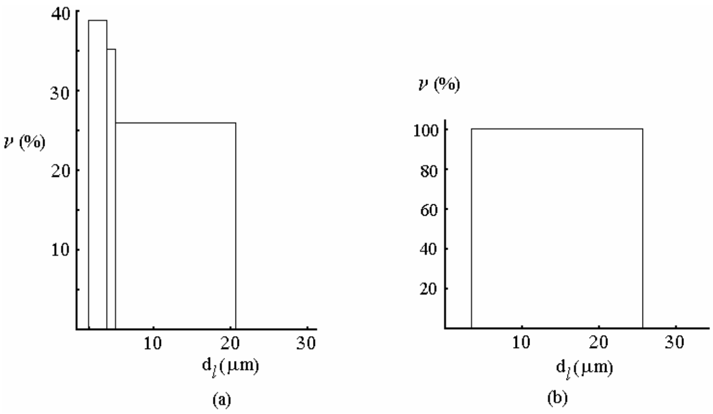

Fig. 2 The relative frequency ν of the pores (of Fig.2) as function of diameter d of the pores, for: (a) micro-sphere m_1; (b) for micro-sphere m_2.

The melt-gases inter-phase tension has been considered equal to that of steel [9], i.e. σ=1.2 N·m^{-1}. The dependence of r_c on S, for $T = T_{melt}$=1573 K is calculated with relation (1) and is shown in Fig.3. Figure 3 shows that the bubbles radius is of minimum 0.56 μm for S=1100, and of maximum 15.8 μm for S=1.3. The gas currents inside the bubbles and the force due to superficial tension can be neglected. The bubbles movement in the micro-sphere wall is considered to be uniform. Then, the resultant of the forces field for one bubble is:

$$\frac{\pi}{6} d_0^3 (\rho_l - \rho_g) \cdot g - 3\pi\eta d_0 U = 0 \tag{2}$$

Out of equation (2) there results the velocity, U of the bubble ascension:

$$U = (\rho_l - \rho_g) \cdot g \frac{d_0^2}{18\eta} \tag{3}$$

where ρ_l and ρ_g are the densities of the melt and of the gas; g is the gravity acceleration and η is the melt dynamical viscosity. For iron, out of Ref.9, there results ρ_l=6958 Kg·m^{-3} and η=6.1·10^{-3}N·s·m^{-2} at T_s=1873 K. The gas ascension velocity U calculated with relation (3), as function of the bubbles diameter d_0 for $\rho_g << \rho_l$ is shown in Fig 3. Figure 3 shows that the gas bubble velocity U range between 25·10^{-9} m·s^{-1} for d_0=2µm and 6,300·10^{-9} m·s^{-1} for d_0=32 µm.

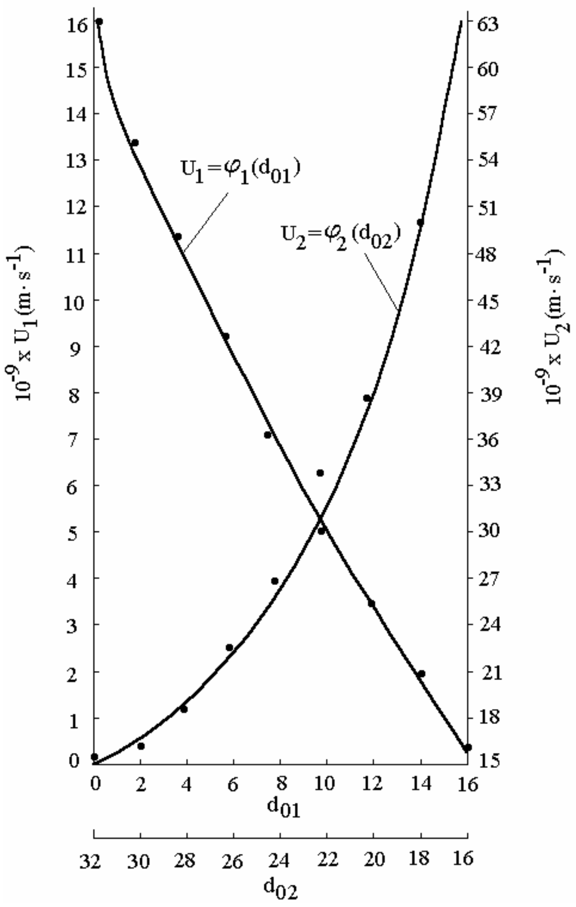

Fig. 3 Velocity U of nitrogen ascension in the micro-sphere wall, as function of the bubbles critical diameter d_o.

Comparing these values with those of the solidification velocities v [10] ,there results that $U << v$. Consequently, pores appear in the micro-spheres solid wall (Fig.1). The volume variation of the iron brought to T=1973 K is of 0.039 [9].

Then, during cooling, the diameter of the pores in the micro-sphere wall changes according to relation $d=0.98 \cdot d_0$. The pores diameter [10] d can be obtained by means of the values from Fig.4 as function of super-saturation S as shown in Fig.4.

As shown in Fig.4, the pores diameter ranges between 1.98 μm for $S_3=1100$ and 31.6 μm for $S_1=1.3$

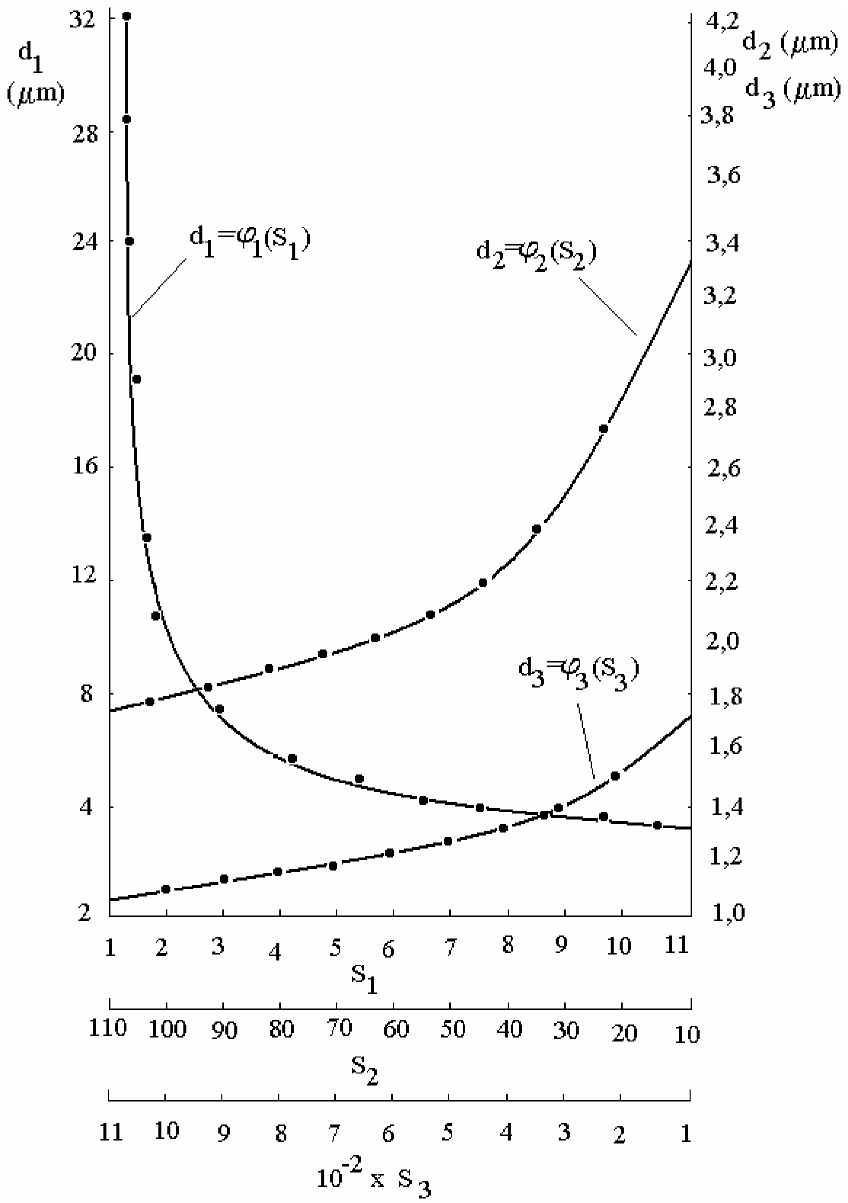

Fig. 4 Diameter d_i(i=1,2,3) of the pores that penetrate the micro-spheres solidified wall, as function of S_i(i=1,2,3) – the melt super-saturation with nitrogen.

Conclusions

- In the mixture of gases where the micro-sphere is formed, nitrogen is the most soluble. It diffuses due to concentration and temperature gradients. Condensation centers are formed. If the condensation germs dimension is greater than a critical dimension, there appear bubbles supersaturating in nitrogen.
- The velocity of the melt bubbles ascension (Fig.3) decreases with their diameter. In all cases, the bubbles ascension speed is smaller than the melt solidification velocity. That is why the micro-spheres solidified wall is penetrated by pores.
- The pores diameter decreases with the nitrogen degree of solubility in the melt (Fig.4). The calculated values range within the values of the pores diameters experimentally determined in Fig.2.

Acknowledgement

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