A Thermogravimetrical Method for the investigation of solid plasma interactions

by

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Abstract

An experimental arrangement has been developed for the investigation of the behavior of a solid body in a thermal plasma. The weight of a sample for instance a hematite sphere is continously measured by an electronic balance with a resolution of approximately 1o µg. The plasma is generated in an induction torch. The Reynolds number of the sphere ranges between 5 and 35 for plasma temperatures between 3000 K to 9000 K and velocities from 5 to 35 m/s. The local plasma properties of enthalpy, velocity and composition were measured by probes. Furthermore the velocity was checked by the track of small graphite particles injected into the flame and by laser-doppler-anemometry. The local surface temperatures of the solid body were determined by infrared pyrometry.

The experimental results show the applicability of this new method for studying the plasma-solid interactions par example for hematite pellets in argon plasma.

Experimental arrangement

The aim of the experimental setup shown in Fig. 1 is to measure the change of weight of a nonreacting or reacting sample, its surface temperature and the properties of the incident plasma flow. From these experimental results conclusions ought to be possible on the transport phenomena, reaction kinetics and the required residence time in actual metallurgical plasma reactors.

Plasma generation

The plasma is generated in a radio frequency induction torch operating 4 MHz and 6 kW exit power. The burner is of a two tube vortex stabilized typ. The distance between the two concentric quarz tubes is 2 mm. The plasmagas is fed from below, heated up and ionized in the coilsection of the torch, it leaves the torch at the top. The burner, which is designed to get a flat enthalpy and velocity profil in the region of the sample, has an outer diameter of approximately 5 cm. It can be moved with a slide and discharges the hot flue gas through a watercooled chimney into an exhaust. The induction coil is connected to the generator by flexible watercooled cable. The hf generator is electronically regulated on the demanded power. All the operation variables were carefully controlled to ensure the reproducibility of the plasma conditions. This has to be done because there is no possibility to control the incident flow while the experiment runs.

Plasmatemperature and velocity and concentration measurement

The plasmatemperature is determined indirectly by measuring the enthalpy of the hot gas by an enthalpy probe. The probe used is a modified calorimetric double-jacket probe with an outer diameter of about 5 mm [1] . The measurements were found to be reproducible within a few percent (< 3%). Because of the quick response of the probe the proper working conditions of the burner were tested in a few minutes by measuring the enthalpy profil in the region of the sample before each run. Fig. 2 shows a typical enthalpy profile. Velocity is computed from total pressure measurement with the same probe. The influence of changing gas density across the boundary layer over the probe surface is corrected by using a mean film temperature. Thereby, we found a good agreement ($< 5\%$) with control measurements made by checking the track of small graphite particles injected into the flame. Within $\approx 1\%$ this result is in accordance with local velocity measurements made with a laser doppler anemometer in forward scattering mode. This device was powered by a 15 mW helium-neon laser. The continious spectrum was filtered out by a small band filter. Fig. 3 shows a typical velocity profil of the torch measured with a Pitot probe. In the case of noncondensing gases the concentration of the argon-hydrogen mixtures could be determined by analysing the gas withdrawn with hot wire analyser.

Gravimetric measurement

The change of weight of a solid body in a thermal plasma is measured at different distances along the axis of the plasma torch. For that purpose the solid, for instance a sphere with a diameter from 3 to 15 mm and a maximum weight of 25 g, is attached with a platinium wire of 0,5 mm diameter to an electronic balance. Because of the possibility of transverse forces a bearing for the suspending wire is required. Moreover, the wire must be protected against the plasma. The solution of this technical problem is shown in Fig. 4. The suspending wire is led in a gasbearing which is designed in such a way that viscose forces are compensated. The bearing is surrounded by a watercooled jacket. Argon is used as the supply gas for the bearing and the massflux is chosen so that the outflow in direction of the sample cools the free part of the suspending wire. In most cases the friction of the bearing can be neglected since the errors are in the order of magnitude of the resolution of the electronic balance, the output of which is recorded on an Y-t recorder.

Sample temperature

The surface temperature is measured by an infrared (2000 mm) pyrometer with a local resolution of less than 0,5 mm^2.

The spectral emissivity was determined before the experiments in another setup. We assumed that the radiation of the plasma in the transmission range of the pyrometer can be neglected. This is in accordance with our observations. Visible phenomena were observed 1oo times magnified by a video camera and recorded on a tape recorder.

Experimental procedure

After the ignition of the plasma torch by a DC arc plasma and stabilizing the discharge the controllers are activated to guarantee stabile plasma properties during the experiment. By moving the burner slide under the probe the total enthalpy and the velocity of the incident flow were measured. After moving the burner under the sample and removing the water-cooled diaphragm the plasma-solid interaction starts. To ensure reoxidation-effects etc. the sample is flushed with argon when the torch is covered by the diaphragm.

Experimental results

Fig. 5 shows a typical weight-over-time-curve for the treatment of a reacting hematite sphere in an argon plasma. The conditions of the experiment are given in the figure. The diagram shows that after exposing the sample to the plasma at time t_a an apparent decrease of the weight occurs because of the flow resistance of the sphere. The curve follows the stepresponse of the balance. The amplitude A_a coincides with computations using the formula given by Lewis and Gauvin [2] . It follows from Fig. 5 that the decrease of weight, which is rapid in the beginning, flattens after about 2o sec to a constant rate of about 15 mg per minute. A few seconds after to small isolated spots of molten material appear on the surface of the sample close to the stagnation point. Later on they grow together and form a liquid drop. Because of the surface tension, the form of the sample varies not much from a sphere.

When plasma is switched off at time t_e from the difference of the stepresponses $A_a - A_e$ at t_a and t_e the change of the drag coefficient can be determined. ΔG is the overall change of weight, which has to be known for individual particles in order to estimate the mean residence time in future plasma reactors.

References

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(2) J.A.Lewis and W.H.Gauvin
AIChE Journal 19 (1973) 982.

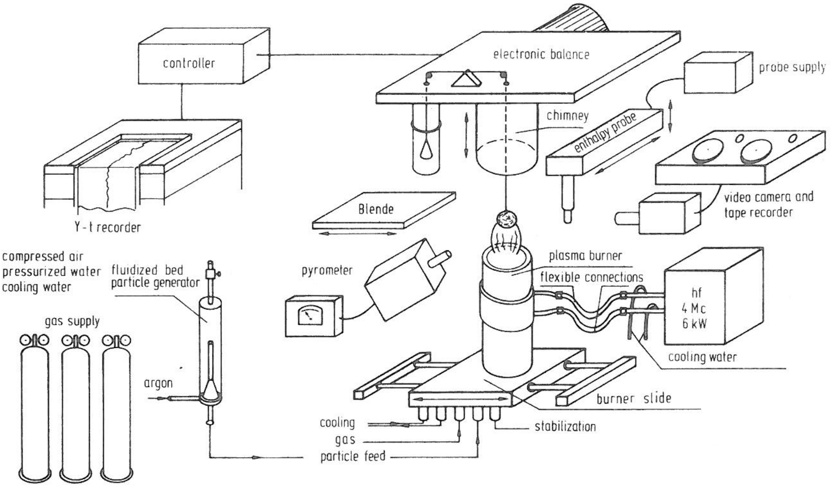

Fig. 1

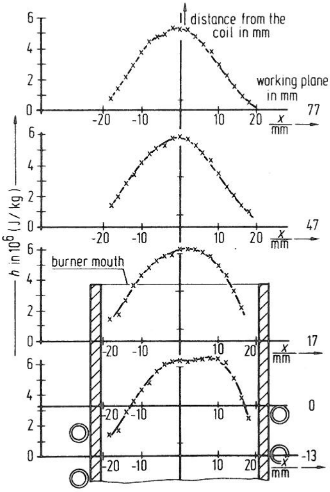

Fig. 2

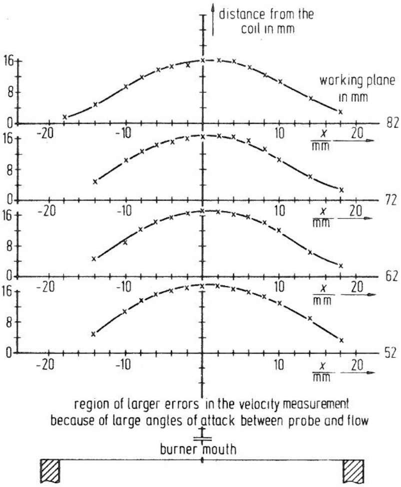

Fig. 3

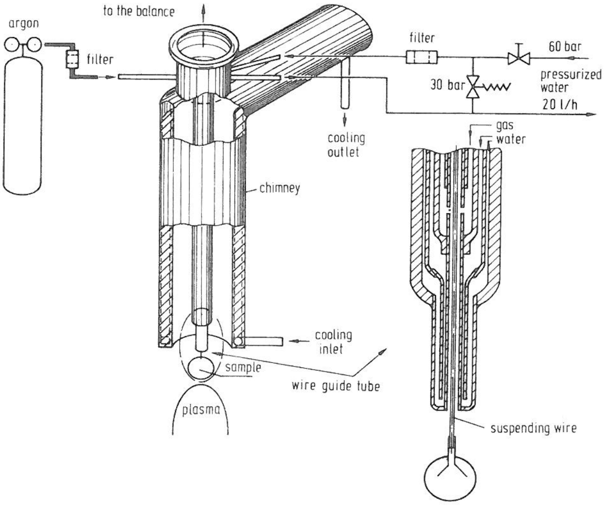
to the balance
argon
filter
filter
60 bar
30 bar
pressurized water
20 l/h
cooling outlet
gas
water
chimney
cooling inlet
sample
wire guide tube
plasma
suspending wire

Fig. 4

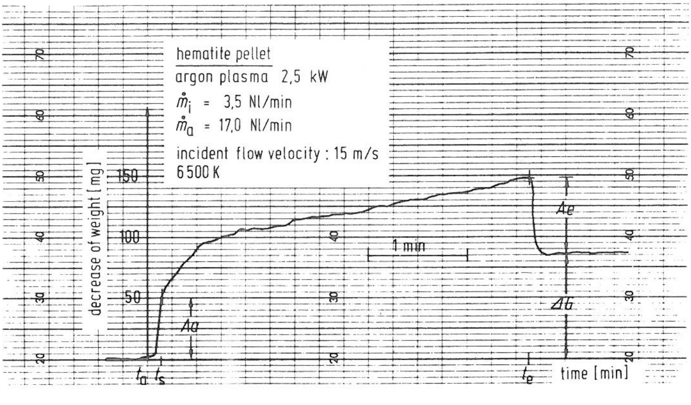
hematite pellet
argon plasma 2,5 kW
$\dot{m}_i$ = 3,5 Nl/min
$\dot{m}_a$ = 17,0 Nl/min
incident flow velocity : 15 m/s
6500 K
decrease of weight [mg]
150
100
50
A_a
A_e
ΔG
1 min
t_a
t_s
t_e
time [min]
70
60
50
40
30
20

Fig. 5