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TEMPERATURE DISTRIBUTIONS OF SOLID PARTICLES IN A PLASMA STREAM (*) (**)

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Résumé. — On a présenté une nouvelle méthode d'analyse statistique de la température des particules solides dans le jet de plasma, le système de mesures et la méthode d'étalonnage. On a mesuré la distribution de température des grains d' Al_2O_3 projetés dans un plasma d'argon-hydrogène.

Abstract. — An original method for the statistical analysis of the temperature of solid particles in a plasma stream is presented. The apparatus and calibration method are described. Temperature distributions of Al_2O_3 particles sprayed in an argon-hydrogen plasma were investigated.

1. Introduction. — Previous papers concerning measurements of the temperature of the particles suspended in high temperature streams can be divided into two groups. The first, comprises papers in which authors measured the mean temperature of the stream of particles. They used different versions of the colour pyrometry method i. e. analyzing the spectral distributions of the thermal radiation of a multiparticle system [2, 3, 4, 5]. The second group comprises a number of papers, in which authors measured the temperatures of single particles [6, 7, 8, 9]. Particles having various temperatures are usually present in the stream. This results from the different trajectories in the jet which, in turn, are caused by the initial velocity and diameter distributions [1]. Therefore, only the discrete statistical analysis of particle temperatures enables investigation and optimization of the heating (and accelerating) conditions of particles in the plasma stream to be made. When photographic detection is employed to determine the total radiation intensity of particles moving so fast that during the exposure time they move a distance much greater than their diameter, the recorded intensity is not only dependent on temperature but also on the ratio of particle diameter to its velocity. English [9] used the discrete version of the colour pyrometry method. The radiation of a single particle passing through the slit was analysed by two photomultipliers operating in two spectral regions and two pulses were recorded with the aid of a double beam oscilloscope. The ratio of the amplitudes of these

pulses is a function of the temperature of the particle and is independent of its diameter and velocity. In the already mentioned paper [9] combusted, pulverized coal had a broad distribution of particle size but an almost uniform temperature.

Size tolerance of powders used for plasma spraying is usually narrow, so that one can assume that all the particles have nearly the same diameter. Therefore, the intensities of the radiation emitted from the surface of single particles of known diameter give information about their temperature distribution.

2. Experiment. — The apparatus shown schematically in figure 1 was used for the analysis of tempera-

FIG. 1. — Diagram of apparatus of the multichannel analyser used for the evaluation of the particle temperatures

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tures of particles during the process of plasma spraying. Images of particles passing across the narrow slit situated in front of the photomultiplier give pulses whose amplitudes are proportional to the intensities of surface radiation integrated over the spectral region of the photomultiplier sensitivity. The photomultiplier has a photocathode sensitive to near infrared (type S1). Thus, pulses after amplification using the logarithmic amplifier are analysed by a multichannel analyser, an Intertechnique DIDAC 4000. The analyser gives the distribution of pulse amplitudes i. e. the count rate per unit of amplitude (channel width) as a function of the amplitude.

The calibration of the apparatus consists in finding the correlation between the particle temperature and the pulse amplitude for a fixed particle diameter. In practice, particles with a well known temperature and diameter and a suitable velocity are not available. Therefore they have to be simulated.

The system employed to simulate the stream of particles comprises a pin-hole, a tungsten ribbon lamp and a chopper. The pin-hole, imitating the particle is placed over the slit. The lamp with a well-known filament temperature is substituted for the source of radiation. The chopper of suitable velocity is placed in front of the slit. In this way the particle of known diameter, temperature and velocity is simulated. By changing the current of the lamp (temperature) the numbers of the particular channels of the multichannel analyser are determined in degrees. In spite of the logarithmic amplification, the calibration curve (particle temperature vs. analyser channel number) is not strictly linear. Thus it is necessary in quantitative analysis, to calculate temperature distributions from distributions of amplitudes obtained directly from the multichannel analyser. For qualitative analysis this is not necessary. The apparatus described allows measurements to be made of temperatures higher than 1 900 K for particles about 50 μm in diameter. The limitation is caused by radiation of the plasma jet scattered in the system and by the radiation of hot gas surrounding the particles. Spectral emissivities of tungsten (calibration) and Al_2O_3 up to the melting point were taken into account. Spectral emissivities of liquid Al_2O_3 were extrapolated. The melting point of Al_2O_3 is about 2 300 K, while the boiling point is about 3 250 K.

Temperature distributions of $\text{Al}_2\text{O}_3 \cdot \text{TiO}_2$ 3 % particles of average size of 47 μm and 63 μm sprayed with the PN-110 PLANCER plasmatron have been measured.

The simplified diagram of the plasmatron is shown in figure 1. The powder was injected into the plasma jet perpendicular to the axis of the nozzle through the channel of 2 mm diameter. The mean initial velocity of the particles depended on the flow rate of the carrier gas. The dependence of temperature distribution of the particles on the distance from the nozzle and on the initial velocity of the particles was investigated. In order

to obtain one temperature distribution, approximately one million particles were analysed during two minutes.

3. Results. — The temperature distributions of particles of 47 μm average diameter are shown in figure 2 for a distance of 150 mm from the nozzle with

FIG. 2. — Temperature distribution of 47 μm particles with initial velocity as a parameter. Operating parameters of the plasmatron : P — 29.8 [kW] ; I — 500 [A] ;

$f_{\text{Ar}+\text{H}_2}$ — 2 890 [Nl/h] ; α — 19 [%].

the initial velocity as a parameter. One can observe displacement of the maxima of temperature distributions and also that the initial velocity favourable for plasma spraying is about 10 m/s.

The temperature distributions of particles of a larger average diameter for the same distance from the nozzle and a higher input power of the plasmatron are shown in figure 3. In this case the advantageous initial particle

FIG. 3. — Temperature distribution of 63 μm particles with initial velocity as a parameter. Operating parameters of the plasmatron : P — 31.9 [kW] ; I — 500 [A] ;

$f_{\text{Ar}+\text{H}_2}$ — 3 040 [Nl/h] ; α — 23 [%].

velocity is also approximately 10 m/s. In spite of the higher power consumption the temperatures of larger particles are lower than those of the smaller ones.

Also the cooling down of the stream of particles can be observed. An example is shown in figure 4 where the

FIG. 4. — Temperature distribution of 63 μm particles with the distance from the nozzle as a parameter. Operating parameters of the plasmatron: $P = 31.9$ [kW]; $I = 500$ [A]; $f_{\text{Ar}+\text{H}_2} = 3.040$ [NI/h]; $\alpha = 23$ [%].

temperature distributions of particles are plotted with the distance from the nozzle as a parameter. This clearly shows that the particles with higher temperatures cool down more quickly than those with lower temperatures.

The sources of systematic errors are: unsatisfactory knowledge of the particle emissivities (especially at the highest temperatures) and a variation of particle diameters during the process itself. The source of statistical errors are: electronic noise, noise from the radiation fluctuation of hot gases, coincidences and differences of particle diameters.

The error analysis shows that the most important effects are the differences of the particle diameters; e. g. particles of 38–45 μm in diameter at a temperature of 2 500 K give pulse rates differing by an amount corresponding to a temperature difference of 100 K.

4. Conclusion. — The powder is introduced into the plasmatron through the channel perpendicular to the axis of the plasma jet. Therefore, wide distributions of particle temperature are observed. These distributions depend strongly on the initial velocity of the powder. The initial velocity of the powder is a very important parameter of the plasma spraying process and should be optimised. A large number of particles (more than 50 percent) are melted in the stream when the operating parameters of the plasmatron and the powder feeder are optimised.

The proposed method for the analysis of temperature distributions of solid (liquid) particles in the stream may be used to investigate the heat exchange between the plasma and particles in a statistical manner. This method applied to the plasma spraying process allows the powder injection, spraying distance and operating parameters of the plasmatron to be optimised. The large number of particles analysed during one measurement gives a very good statistical value. Continuous visualization of data on the monitor of the analyser allows the operating parameters to be optimised in a quick and easy way.

Glossary of symbols.

$\bar{V}_0$	the average initial particle velocity.
z	the distance from the plasmatron nozzle.
T	particle temperature.
$\frac{dN}{dT}$	the ratio of quantity of particles per unit temperature.
$f_{\text{Ar}+\text{H}_2}$	flow rate of argon-hydrogen mixture in normal liters per hour.
α	hydrogen content in mixture in percent.
P	input power in kilowatts.
I	current in amperes.

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