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Frequency distribution of dust particle size after removal of oxide on carbon steel using low-pressure arc

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Abstract

Low-Pressure-Arc (LPA) technology promises to be of use as a new surface decontamination technology for radioactive metal wastes. The radioactive dust generated during a LPA process can cause re-contamination of wastes, therefore the dust needs to be collected. As a fundamental study of the collection of radioactive dust, we applied a LPA to the oxide film at pressures of 13, 190, and 8000 Pa in an argon atmosphere, and investigated the frequency distribution of dust particle size adhering to the specimen. By establishing a method of evaluating the frequency distribution of dust particle size from SEM photographs using non-parametric test, we obtained the following results on the dust adhering to the specimen; (1) more than 80% of the measured particles are distributed within a size of 0.2–1.2 μm to the total number of particles; (2) with the higher pressure, the number ratio of small particles declined, and the number ratio of large particles increased, especially near the track of cathode spot; (3) the further the distance from the removal area, the lower the number ratio of large particles becomes; (4) the ratio of the weight of the dust adhering to the specimen increased from 5% to 15% with the pressure.

Keywords: Low pressure arc; Dust collection; The frequency distribution of dust particle size

1. Introduction

Radioactive solid wastes are generated in the operation and maintenance of nuclear power plants. Most of these wastes are buried after solidification by melting or by cementing, etc. However, from the viewpoint of cost saving and efficient use of natural resources, greater efforts need to be made to simplify the disposal and recycling of waste by surface decontamination. Surface decontamination becomes even more significant in the decommissioning of nuclear power plants.

We showed a LPA as an effective surface decontamination technology for radioactive solid wastes with corrosion products formed on a metal surface under condition simulating primary cooling water in a boiling water reactor [1]. In a LPA process, the oxide film melts and evaporates, then forms droplets and vapor flows gushing from the cathode spots [2]. These droplets and vapor-condensed material accumulate on the anode surface, on the surface of the object being treated, or on the chamber wall as film and dust. The radioactive dust generated during a LPA process can cause re-contamination of the object being treated; therefore, it must be collected before re-contamination.

A LPA phenomenon was heavily dependent on the pressure in the chamber [3]. Thus we need to obtain the dependence of the frequency distribution of dust particle size on the pressure to apply dust collection method by gas flow. There are a number of papers describing the dependence of the frequency distribution of synthesized particle size on the pressure in the chamber in research fields of synthesis of fine particles [4–6]. However a LPA has never been applied in these studies. Therefore as the first stage of investigating the dust collection methods, we investigated the frequency distribution of dust particle size generated during removal of oxide film on a metal surface using a LPA.

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2. Experimental conditions

2.1. Experimental set-up

As shown in Fig. 1, the experimental set-up is composed of a vacuum chamber with electrodes inside, a DC power supply, an evacuation system employing a rotary pump, and a water circulation system to cool the anode. The specimen material is carbon steel (SS400) covered with an oxide film. The dimensions of the specimen are 50 × 50 mm wide and long, and 8 mm thick. The oxide film is about 20 μm thick measured by SEM photographs [1]. The specimen is connected to the negative polarity of the power supply and serves as a cathode. The magnitude of the arc current is adjusted to DC 10 A. The anode is made of copper with a diameter of 47 mm and has the hemispherical projection of a diameter of 10 mm. All areas of the anode except the projection were covered with ceramic plate for electrical insulation. The distance between the anode and the surface of the specimen (cathode) is 5 mm. After exhausting the gas in the vacuum chamber, pure argon gas is introduced into the chamber. The pressure inside the chamber is controlled at 13, 190, and 8000 Pa. There is no sucking or blowing flow in the chamber during processing. Arc duration time is 1 s. These experimental conditions allow the removal area to be narrowed, making it easier to estimate the scattering distance of the dust from the boundary of the removal area, as shown in Fig. 2 described in Section 2.2.

2.2. Analysis and method of estimating the relative frequency of dust particle size

After the processing, we took SEM (scanning electron microscope, JEOL, JSM-T220) photographs of the dust on the specimen to obtain the frequency distribution of dust particle size. The shape of the dust was considered as ellipse, the particle size was defined as the average of the longer diameter and shorter diameter of observed particle. The minimum particle size confirmed by SEM was almost 0.2 μm, and the observed area of each photograph around 30 μm^2. The distances of the observation spot (X) were 0, 5, and 10 mm from the boundary of the removal area, and we took five SEM photographs for each observation spot as shown in Fig. 2. The SEM photograph was converted into binary using an analysis software [7]. The threshold for this binarization was determined using discriminant analysis [8]. In this method, the threshold was determined so as to make each dispersion of two sets divided by the threshold as small as possible, and to make dispersion between the two sets as large as possible. Finally, we can get the distribution frequency of dust particle size.

The propriety of the particle number was examined by non-parametric tests [9,10], because the frequency distribution of dust particle size is not a normal distribution. It was revealed that a level of significance of 5% was evaluated using two kinds of non-parametric tests. One is the Mann–Whitney test [9], which examines the median distribution. The other is the two-sample Kolmogorov-Smirnov test [10] that examines dispersion of the distribution. We judged that a sufficient number of particles were obtained in five SEM photographs.

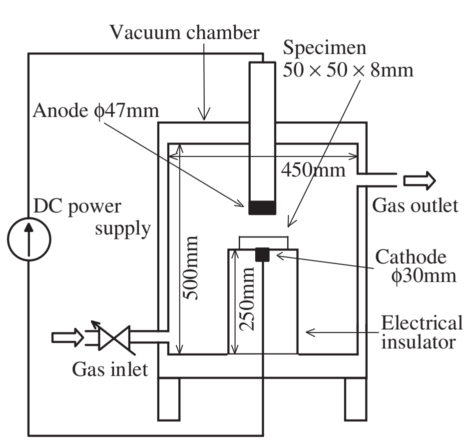

Fig. 1. Experimental set-up.

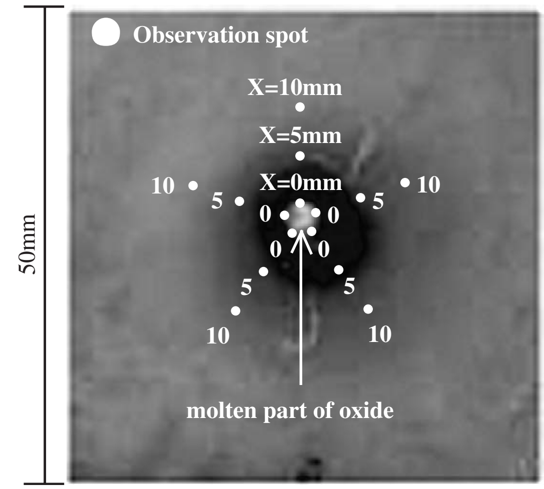

Fig. 2. Distances of observation spot (X) on cathode.

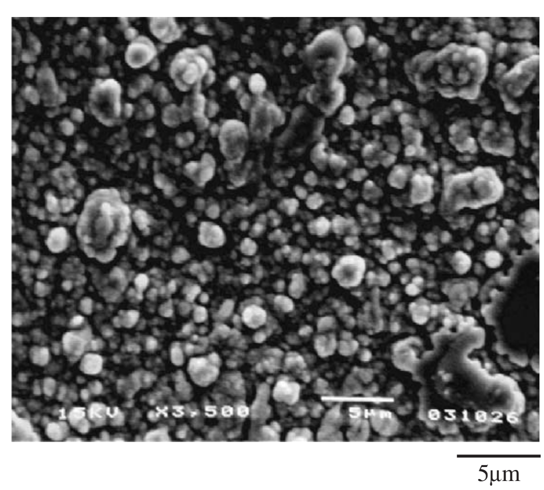

Fig. 3. SEM photograph on cathode (X = 0 mm at 8000 Pa).