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Thin Solid Films 506–507 (2006) 337 – 341

thin solid films

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Surface variation caused by vacuum arc cleaning of organic contaminant

Masaya Sugimoto *, Koichi Takeda

Faculty of Systems Science and Technology, Akita Prefectural University Honjo, Akita 015-0055, Japan

Available online 9 September 2005

Abstract

Arc in a vacuum was applied for surface cleaning of metal with organic contamination. At the time of the cleaning, the metal surface layer was molten and defected by vaporizing and quenched because of rapid heating and cooling caused by cathode spot motion, which resulted in surface change after the cleaning. The influence of contaminant density or discharge current on change of surface was experimentally investigated. It is revealed that the post-treatment surface condition strongly depends on both these factors.

Keywords: Vacuum arc cleaning; Cathode spot; Surface variation; Organic contaminant

1. Introduction

The surfaces of machined metal products are generally contaminated with various kinds of organic matter. In many cases, these products receive final surface treatment such as coating. Because the organic matter on the surface prevents those surface treatment layers from adhering to the pure metal surface, cleaning and degreasing treatments prior to coating are very significant [1].

We have suggested the application of arc discharge in a vacuum for metal surface cleaning [2,3]. When arc discharge is established in a vacuum, small bright 'cathode spots' appear on the cathode and continuously change their positions [4–7]. Current flows through the spots, and one spot thus carries a few tens of amperes [2,6]. Because the dimensions of these spots, estimated to be larger than 1 μm by crater size and less than 100 μm by their track left on the stainless covered with oxide layer 5 μm in thickness, are very small, a huge energy density $10^{10}\sim10^{14}$ W/m^2 is realized at the sites of the total spots [2,7]. Most kinds of matter on the cathode surface are immediately vaporized and removed by such an enormous energy density. Our method uses this mechanism for the metal surface cleaning. Results of previous experiments on vacuum arc metal surface cleaning have shown that it is very promising because it successfully removes both mill scale and organic matter on the metal surface [2,8]. In addition, because the surface layer is also heated, melting and quenching of the metal surface occur as the spots move, which results in activating and roughening the surface [7,9]. This effect is very appropriate as the preparation for the following metal surface treatments. Because the cathode spot causes surface variation and the behavior of the cathode spot is affected by the contaminant, it can be understood that the contaminated condition or cleaning parameter influences the cleaned surface. However, this aspect has never been studied before, although we previously investigated the cleaning characteristics for different surfaces and cleaning conditions [2,7,10,11,12,13].

In this research, surface variation caused by vacuum arc cleaning of organic contaminant is studied. The weight and depth of the removed metal surface layer by cathode spots are investigated as is the surface roughness.

2. Experimental setup

The test sample used in this study was a 100 mm × 100 mm and 3 mm thick stainless (SUS304) plate, homogeneously covered with organic contaminant. Liquid paraffin was selected as the contaminant matter here because it handles well and its chemical structure is simple; It is a mixture of a few kinds of alkane C_nH_{2n+2}, in which the averaged value of "n" is about 15. Because liquid paraffin

* Corresponding author. Tel.: +81 184 27 2117; fax: +81 184 27 2188.
E-mail address: sugimoto@akita-pu.ac.jp (M. Sugimoto).

0040-6090/$ - see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.tsf.2005.08.078

has a large viscosity, it is difficult to distribute it uniformly. In order to spread it over the surface, the sample plate was dipped into a pool of liquid paraffin diluted with petroleum benzine and then left in the air to volatilize the dilutor. The weight of the test sample was measured before the dip and the cleaning, and the weight and surface density of the paraffin were calculated from these values. The dilution ratio was varied from 10 cm^3 to 200 cm^3 for 100 cm^3 petroleum benzine, which resulted in a weight change of liquid paraffin on the surface.

In the present study, a portable vacuum arc cleaning device, which consists of a vacuum chamber with an anode, and an evacuating and a water cooling system, was used. The experimental setup is shown in Fig. 1. The vacuum chamber is shaped like a cup, the inner diameter of which is 50 mm, which contains a water-cooled copper cylindrical anode that has a spherical surface at the edge of the cathode side as shown in the figure. Before the test sample was cleaned, the vacuum chamber was set over the sample surface and evacuated by a rotary pump to about 50 Pa; no gas was conducted. The gap between the sample surface and the anode was 70 mm. Arc discharge was ignited with high frequency high voltage and sustained by a dc power supply. Discharge current was controllable up to 120 A, while its voltage was almost fixed between 40 and 50 V. The pressure in the chamber increased to 200∼300 Pa immediately after the breakdown and was almost constant until the completion of discharge. The cleaning duration was fixed at 6 s in this research. In this method, the cleaning process starts near the center of the covered region and gradually moves toward its periphery [8]. In the case of long treatment such as that 10 s or longer, because the cathode spots stay on the cleaned region in the final period, the precise weight removal rate of paraffin cannot be measured. On the other hand, in the case of short treatment such as that less than 5 s, the shape of the cleaned region is irregular and it is difficult to measure the value of the cleaned area. Judging from these points, a treatment time of 6 s was selected.

After the cleaning, the cleaned area of the test sample was measured and the weight loss of paraffin was estimated using the surface density of liquid paraffin. Further, the sample was again weighed after the residual paraffin on the surface was entirely removed by ultrasonic cleaning in order to determine the weight defect of the stainless plate. Surface roughness (center-line-average-height) R_a of the cleaned surface was also measured with a surface roughness tester (MITSUTOYO Surftest SJ-401).

3. Experimental results and discussion

In the case of removal of oxide, the cleaning proceeds in a random manner [2,7,10]. In contrast, in the case of liquid paraffin removal, the cleaning proceeds in an orderly fashion from the central region to the periphery [8]. The reason for this difference is not yet understood. It is very easy to distinguish the cleaned area because it looks bright in contrast to the peripheral dark brown region. In the dark brown region, the liquid paraffin appeared changed, which is probably due to carbonization. Although pure liquid paraffin is an insulator, it has finite conductivity because of the carbonization at the beginning of the discharge, and therefore the arc can be generated after carbonization. The cathode spots stay in the paraffin region while there is residual paraffin near the center. They gradually move to the periphery as the cleaning of the central region is completed. However, it becomes hard for them to move all the way to the periphery, and they tend to stay on the metal surface until completion. Fig. 2 shows paraffin surface density variation of surface removal rate A which means the cleaned area per second. On the other hand, weight removal rates W_{par}, W_{sus} and $W_{par}+W_{sus}$ for various values of paraffin surface density are shown in Fig. 3. Here,

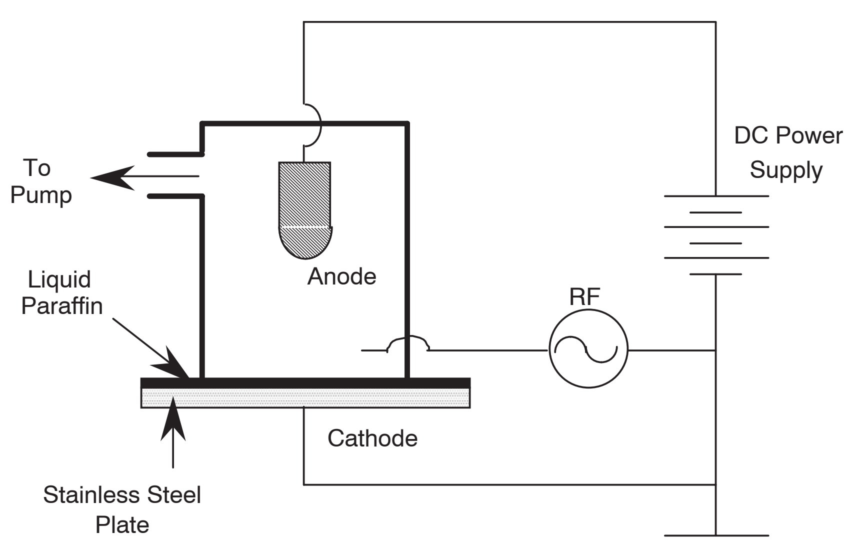

Fig. 1. Schematic view of experimental apparatus.