Removal of Machine Oil from Metal Surface by Mesoplasma Jet under Open Atmosphere

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Received November 28, 2008; revised March 23, 2009; accepted April 6, 2009; published online August 20, 2009

An attempt was made to employ the plasma-energized jet (PEN-jet) generated by pulsed arc discharge, one of the atmospheric-pressure mesoplasmas, for removal of machine oil from the surface of electrically-grounded aluminum (Al) alloy substrate under open atmosphere. Three types of nozzle configurations were examined; a metal nozzle, ceramic nozzle, and electrically-floated metal nozzle. Electric input power to the pulsed arc plasma discharge was 700 W constant. First, free-burning of the PEN-jet was observed as a function of air gas flow. When the PEN-jets were irradiated to the clean substrate, the PEN-jet with the metal nozzle caused substrate damage by the arc spot due to transferring arc discharge. Then the PEN-jet with the ceramic nozzle was irradiated to the oily substrate. The adhesion strength of sealant and water contact angle of the treated surface were then measured. As a result, these values of the oily substrate treated by the PEN-jet were almost the same as those of clean substrate. The treated surface was analyzed by Fourier transform infrared spectroscopy, Raman spectroscopy, and reflectance spectroscopy. Their spectral profiles clearly indicated oil removal from the surface by PEN-jet.

DOI: 10.1143/JJAP.48.08HH03

1. Introduction

In the motor vehicle manufacturing process, machined parts are bonded or sealed with polymer glue or sealant, for example. In such case, prior to applying the glue or sealant, the residual machine oil on surfaces of machined metal parts used to be washed out or removed with an appropriate organic solvent. However, waste fluid of used solvent and simultaneously generated volatile organic compounds should not be emitted from the environmental standpoint. In order to do away with such wet processes, a dry process using plasmas has been investigated.[1–5] However, the treatment time was long[1] or a process chamber was necessary.[1–5] Therefore, chamber-less, open atmosphere treatment process has been awaited as an alternative.

The present study investigated the feasibility of employing atmospheric-pressure mesoplasma jets (APMJ) for removing machine oil from metal surfaces under open atmosphere without chamber. The temperature of APMJ is midway between those of a cold plasma (approximately room temperature) and thermal plasma (over 1,000 °C; for example, welding plasma, thermal spray plasma, arc discharge in electrical circuit breaker), ranging from room temperature to approximately 1,000 °C. We have studied APMJ generation using pulsed arc and their applications so far.[6–12] There are two types of APMJ using pulsed arc; a new plasma-energized jet (PEN-jet) with a pen shape type and the long-known gliding arc.[12] As for removal of the machine oil, comparably higher temperature is required. Thus, in this study, the PEN-jet was employed, since its temperature is relatively higher than that of the gliding arc. The nozzle type of the PEN-jet which was able to avoid the damage on metal substrate due to arc spot appearance on the surface was considered based on experimental analysis. In order to establish judgment system under open atmosphere whether the oil was removed or not without contact to the surface, the surface was optically analyzed.

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2. Experimental Methods

In present study, three type PEN-jets with different nozzle configurations were tested. Schematic diagrams of the PEN-jet and experimental setup are depicted in Fig. 1. The details of nozzle configurations [metal nozzle, alumina (Al_2O_3) ceramic nozzle, electrically-floated metal nozzle] are also shown in Fig. 1. Electrical conditions for generating pulsed arc discharge in PEN-jet were constant at power, 700 W at a wattmeter; pulse frequency and width, 20 kHz and 4 μs at pulse modulator). The experimental parameter was air flow rate (10, 30, and 60 L/min). The air regulated at 0.45 MPa was supplied by a compressor with dryer through the reservoir tank. The PEN-jet was observed with a digital camera [Panasonic DMC-LX1; exposure time, 1/5; F number, 4.9; International Organization for Standardization (ISO) sensitivity, 80] and high-speed color video camera (Photron Fastcam-Spectra/UV). The electrical signal of arc voltage V, arc current through body electrode I_1, and current through an electrically-grounded substrate I_2 were measured with a digital oscilloscope (Yokogawa Electric DL-1540L). The trigger in the oscilloscope was output as the trigger signal to the video camera for synchronous measurement and observation. The plasma radiation 5 mm away from the exit was observed with a spectrometer (Soma Optics Fastevert S-2400; wavelength range, 250–900 nm; resolution, 1.3 nm).

The substrate used was aluminum (Al) alloy (A5054, $20 \times 20\,mm^2$, 1 mm thick). The as-received substrate was washed with liquid neutral detergent and rinsed in an ultrasonic bath with distilled water, which we call a clean substrate in this paper. The machine oil used was for an ironworker drill (AZ 852; specific gravity, 0.94). The oil was dropped on the substrate with a micropipette and gently spread over the surface. 0.5-mg/cm^2 of the oil was on the substrate. The substrate was treated 5 mm away from the PEN-jet exit, and the traverse speed of the substrate against the PEN-jet was 10 mm/s. The room temperature and relative humidity were 23 °C and 80%, respectively.

