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Constituent analysis of aerosol generated from die sinking electrical discharge machining process

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ABSTRACT

This paper aims to study the influence of process parameters on the breathing zone concentration of the aerosol generated from the electrical discharge machining process using Taguchi methodology. Peak current, pulse duration, dielectric level above the spark location and flushing pressure were the process parameters considered in this work. Characterization of the components present in the aerosol and its morphology are also presented. The metallic particles present in the aerosol were analyzed using Inductively Coupled Plasma (ICP). Gas Chromatography coupled with Mass Spectrometry (GC–MS) was used to analyze the hydrocarbon components attached to the aerosol. Scanning Electron Microscopy (SEM) and X-Ray Diffraction (XRD) techniques were applied to study the morphology of aerosol. Analysis of the results showed that the peak current and the pulse duration are the most significant parameters on the breathing zone concentration of aerosol. Investigation using ICP revealed that the major portion of aerosol (about 69%) constitutes metallic particulates. GC–MS analysis of the aerosol samples indicated the presence of about 20 different hydrocarbons. Morphology studies showed that the particulates are of spherical shape with average sizes ranging from 20 to 29 nm. The control measures to minimize the risk of exposure have also been discussed in this paper.

Keywords: Electrical discharge machining; Aerosol; Taguchi methods; Occupational exposure; Nanosized particles

1. Introduction

Manufacturing operations are linked with inevitable risks to the operators and environment. It is the task of the industry to keep them within acceptable limits. Exposure to airborne particulates is considered to be an important occupational hazard in manufacturing industry (Ross et al., 2004; Brouwer et al., 2004). The characteristics of such aerosols depend on the types of operation, materials used and processing parameters. Occupational exposure data for a specific operation are useful in assessing workplace hazard and in identifying control measures to reduce exposure.

Die sinking electrical discharge machining (EDM) is one of the most important manufacturing processes in the die and mold manufacturing industry and is furthermore applied to various branches like electronic, automotive, aerospace and surgical components' industries. EDM uses the heat energy of an electric spark struck between two conductive electrodes (workpiece and tool) for material removal, which causes some of the work material to melt and even evaporate. Between the anodic tool and cathodic workpiece there is a non-conducting dielectric, for instance a hydrocarbon fluid like a mineral oil. In the area of highest field density an electrical conductive plasma channel builds up with temperatures up to 20,000K (Eubank et al., 1993). As the spark collapses, the evaporated metal and part of the molten metal is carried away by the dielectric fluid which is flushed with pressure. Along with the various advantages, the EDM process has several hazard potentials viz., emission of gases and aerosols, fire, explosion, degreasing effect and electrical hazard (Tonshoff et al., 1996). Among these hazard potentials, that of aerosol is one of the most important needing special attention. Aerosol is created in the EDM process by the vaporization of work piece and tool materials at the spark location due to the generation of very high temperatures. Apart from the metallic particles, reaction-products of the dielectric fluid can also be attached to the

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Nomenclature

C_A	concentration of aerosol in the work atmosphere (mg/m^3)
C_M	concentration of metal in the work atmosphere (mg/m^3)
C_S	concentration of metal in the sample (mg/l)
I	peak current (A)
L	average particle size (Å)
SS	sum of squares
$(SS)_p$	sum of squares of process parameter
$(SS)_T$	total sum of squares
$\hat{S}$	corrected sum of squares
V	variance
V_S	volume of sample (ml)
W_a	weight of the filter paper before sampling (mg)
W_b	weight of the filter paper after sampling (mg)
d.f.	degrees of freedom
f_p	flushing pressure (kg/cm^2)
h	dielectric level (mm)
j	level number of the process parameter
m	number of experiments in the orthogonal array
n	number of repetitions in a trial
p	parameter
$s_{\eta j}$	sum of the S/N ratio of the parameter at level j
t	repetition of each level of the parameter
t_p	pulse duration (μs)
t_s	sampling duration (min)
v	sampling speed (l/min)
y_i	the measured output value for the ith repetition
β	full width at half maxima (FWHM) of the peak (rad)
η	signal to noise (S/N) ratio
η_m	total mean of S/N ratio
η_i	mean S/N ratio for the ith experiment
λ	X-ray wavelength (Å)
θ	Bragg's diffraction angle
ρ	percent contribution of factor

aerosols. The occupational hazard potential of this aerosol depends on its concentration in the breathing zone of the operator and its constituents.

Although the mechanism of formation of the aerosol may be similar, the characteristics and quantity of emission of EDM workstations is widely varied and is dependent on the process parameters, such as peak current, voltage, pulse duration, flushing pressure, dielectric level above the spark location, workpiece, tool and dielectric materials and the type of exhaust system used. Hence, a systematic investigation of EDM process parameters on emission became necessary to address environmental and occupational concerns as well as minimizing the total aerosol released from this process. Such methodical study pin points suitable control measures to minimize occupational exposure.

Investigations concerning the environmental and safety aspects of the EDM process are few in number. Possible constituents of emission from the process using hydrocarbon and water based dielectric fluids were presented by Bommeli (1983). Jose et al. (2008) reviewed the study on occupational and environmental problems associated with this process. Yeo et al. (1998) proposed an analytical method for the environmental impact assessment of the process. Jose et al. (2010) carried out a systematic assessment on the occupational and environmental hazards of the EDM process to explore its causes effects and remedies. Investigations by Evertz et al. (2006) have revealed that process parameters such as workpiece, tool, dielectric level and current have a strong influence on the quantity of toxic substances emitted. Their approach has been to vary one parameter at a time and to study its effects. However, because of the complex nature of the EDM process and interaction of the process parameters, a systematic multivariable study on aerosol emission is necessary to give a clear idea about its correlation and mechanism. In such multivariate problems, a well known statistical technique called design of experiments (DoE) is applied; several methods such as full factorial design, response surface design and Taguchi methods are the commonly used DoE techniques (Montgomery, 2004). Among these techniques, Taguchi methodology can help determine the influence of process parameters by conducting least number of experiments. Since the analysis of aerosol constituents' from EDM process requires large investments of time and money, Taguchi methodology is the most appropriate methodology to solve the problem. There is however, no reference reporting the use of Taguchi methods of DoE for emission studies on EDM. Recent studies have showed that the shape, number and surface area of particulates are also significant while assessing the risk of exposure (Tsuji et al., 2006). However, no reported investigation concerning the morphology of aerosol generated from this process was available. Moreover, the reported information on the experimental investigation of emission, while using kerosene, which is a commonly used dielectric fluid in the die sinking EDM process, is limited.

The present investigation was conducted in a laboratory environment of die sinking EDM machine using kerosene as a dielectric fluid. This work had multiple objectives; the first was to analyze the influence of process parameters on the breathing zone concentration of respirable aerosol generated from the EDM process using Taguchi methodology. The other objectives were to; analyze the constituents of aerosol generated from the process; study the morphology of the particulates; suggest the control measures to reduce the risk of aerosol exposure.

2. Materials and methods

2.1. *Design of experiment*

Taguchi methodology for statistical design of experiments was used in this study to explore the influence of process parameters with regard to the breathing zone concentration of aerosols. The Taguchi method utilizes orthogonal arrays to study the effects of a large number of variables with a small number of experiments. Using orthogonal arrays significantly reduces the number of experimental configurations to be studied. The most important objective of using Taguchi method in this study was to identify the key factors that make the greatest contribution to the variation in occupational exposure. The major steps of Taguchi method used in this study:

- First step was the selection of process parameters that likely influence the aerosol emission from the EDM process. The peak current, pulse duration, flushing pressure and dielectric level were the process parameters considered in this study. Three levels within the operating range for the