Process Safety and Environmental Protection 92 (2014) 739–749

Contents lists available at ScienceDirect

Process Safety and Environmental Protection

journal homepage: www.elsevier.com/locate/psep

Influence of workpiece materials on aerosol emission from die sinking electrical discharge machining process

S. Thiyagarajan[a], S.P. Sivapirakasam[a,*], Jose Mathew[b], M. Surianarayanan[c], K. Sundareswaran[d]

[a] Department of Mechanical Engineering, National Institute of Technology, Tiruchirappalli, India
[b] Department of Mechanical Engineering, College of Engineering, Kallooppara, Kerala, India
[c] Cell for Industrial Safety and Risk Analysis, Central Leather Research Institute, Adyar, Chennai, India
[d] Department of Electrical and Electronics Engineering, National Institute of Technology, Tiruchirappalli, India

ABSTRACT

Simultaneous investigation of environmental emissions and machining aspects of electrical discharge machining process is essential for achieving hygienic and efficient machining. The main objective of the present work is to experimentally investigate and analyze the aerosol emission rate and the material removal rate from a die sinking electrical discharge machining process for three commonly used work piece materials viz., tool steel, mild steel and aluminum using Taguchi methodology of Experimental Design in order to suggest suitable process conditions for green manufacturing. The aerosol emission profile of all workpiece materials was found to be closely related to the material removal profile. A significant variation in emission and material removal rate was observed for workpiece materials which may be accorded to the variation in melting and vaporization temperatures. It was also observed that majority of aerosol constituents evolved from workpiece materials and that the constituents with low melting points were having high relative concentration in the aerosol emitted. The study introduced a parameter, the relative emission rate for comparing the emission for various process parameters and workpiece–tool material combinations. The favorable machining parameters for each material were then identified by employing signal to noise ratio analysis of the relative emission rate.

Keywords: Electrical discharge machining (EDM); Emission; Aerosol; Taguchi methodology; Relative emission rate

1. Introduction

Electrical discharge machining (EDM) is an important non-traditional manufacturing process, typically used for machining very hard and brittle materials. The schematic diagram of EDM process is shown in Fig. 1. The basic principle in the EDM is the conversion of electrical energy into thermal energy through a series of electrical discharges occurring between the electrodes (work piece and tool) immersed in a dielectric fluid. A series of voltage pulses usually of the order of magnitude 20–100 V are applied between the electrodes with a frequency of 5 kHz to 5 MHz. The peak current and pulse duration are the main process parameters of EDM governing the process energy. The dielectric fluid stored in a sump tank is flushed continuously through the inter-electrode gap using a pump. The height of dielectric surface above the spark location is termed as dielectric level. As the pulse in the EDM process begins, the passage of pre-breakdown current heats the dielectric liquid in the inter electrode gap. When the dielectric strength of the liquid in the gap is exceeded, breakdown occurs and initiates a plasma channel. This plasma channel expands during the following pulse on time. The growth of the plasma channel is restricted by the surrounding dielectric fluid, which in turn causes a higher concentration of discharge

* *Corresponding author at*: Department of Mechanical Engineering, National Institute of Technology, Tiruchirappall 620015, India. Tel.: +91 431 2503408; fax: +91 431 2500133; mobile: +91 9944547215.
E-mail addresses: spshivam@nitt.edu, spsivam@yahoo.com (S.P. Sivapirakasam).
Received 27 June 2013; Received in revised form 7 January 2014; Accepted 13 January 2014
Available online 24 January 2014
0957-5820/$ – see front matter
http://dx.doi.org/10.1016/j.psep.2014.01.001

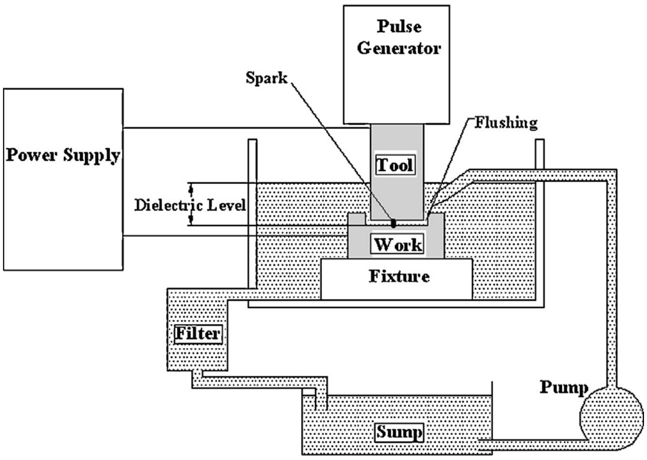

Fig. 1 – Schematic diagram of EDM process.

energy in a very small volume, which causes the erosion. The cumulative effect of a succession of sparks spread over the entire work piece surface leads to its erosion to a shape which is approximately complimentary to that of the tool.

The EDM machines used in small and medium sized industries are manually operated. An operator will be simultaneously operating more than one machine. EDM installations are open systems in which the dielectric tank is exposed to work atmosphere. The high temperature developed in the discharge channel of the EDM process causes the generation of toxic reaction products and metallic particulates that will be released into the work environment with the potential of causing severe occupational and environmental problems (Bommeli, 1983; Tonshoff et al., 1996). Since the discharge temperature of the EDM process depends on peak current and pulse duration, the deviations of these parameters can influence the emission. The flushing pressure and dielectric level that affect the dynamics in the dielectric may also influence the emission.

A variety of tools and dielectric materials are being employed by the manufacturer based on the work material and the desired machining performance of EDM process. Generally, one material among, copper/tungsten, alloys of copper or tungsten/graphite is used as the tool electrode and mineral oils/deionised water/commercial hydrocarbon oils are used as the dielectric fluid. Kerosene, a blend of hydrocarbons, is widely used in this process due to its high flash point, good dielectric strength, transparent characteristics, low viscosity and low specific gravity (Bhattacharyya et al., 2007). Different combinations of workpiece, tool and dielectric fluids also result in the variation in the aerosol emission and its constituents (Evertz et al., 2006).

In order to provide suitable control measures to safeguard the operator, an estimate of the concentration of emissions is required. The concentration of aerosol in the work atmosphere depends on the rate at which it is emitted from the dielectric surface. The emission rate can be controlled by using effective fume extraction systems. Small and medium sized EDM machines considered in this study are not equipped with fume extraction systems. Though the sophisticated EDM machines are using fume extraction systems, there is a lack of a process specific design due to the insufficient knowledge on the emission with varying process parameters. This draws the attention for a systematic study of emission with varying process parameters at different combinations of workpiece materials. Such a study could further help in selecting the best combination of process parameters that could reduce the emissions.

Good information is available on aerosol exposure on machine shop workers (NIOSH, 2003a; NIOSH, 2007; Jaakkola et al., 2009). Nevertheless, literature on experimental investigation of emission from the EDM process is scanty. The first report on emissions from the EDM process was by Bommeli (1983). Through experimental investigation, he identified the components of emission generated from EDM process when hydrocarbon based and water based dielectric fluids were used. The hydrocarbon-based dielectric fluids caused emission of aliphatic, aromatic, polycyclic aromatic hydrocarbons, carbon and metallic particles, whereas water-based dielectric fluids caused emission of toxic constituents like ozone, CO and metallic particles. A comprehensive review of safety and environmental aspects of the EDM process was presented by Tonshoff et al. (1996). Leao and Pashby (2004) presented the environmental impact resulting from the use of die sinking EDM process. It was observed that emission of toxic substances and generation of toxic wastes was the important environmental issues that caused the health problems to the operators and land and water pollution. The study depicted that consumption of high amount of energy by the EDM process was one of the factors that led to environmental problems.

In a manufacturing industry, though the emission is a criterion, productivity and quality aspects of the process are also vital (Tan et al., 2002). In case of the EDM process, material removal rate is one of the significant performance parameters that need special attention. By varying process parameters at different combination of materials from the perspective of reducing exposure may at the same time, considerably affect performance characteristics of this process. Therefore, a simultaneous study of the emission rate and the MRR of the process become inevitable. Since the analysis of emissions is both expensive and time consuming, the Taguchi methodology of Design of Experiment (DoE) was adopted to limit the no of experiments in this work (Peace, 1992).

The present investigation was conducted in the die sinking EDM machine, in a laboratory environment using kerosene as a dielectric fluid. This work had multiple objectives; the first being to experimentally investigate the aerosol emission as well as the material removal rate from die sinking electrical discharge machining process for three different commonly used work piece materials viz., tool steel, mild steel and aluminum. The other objectives were to; analyze and compare the constituents of aerosol emission generated for each of the work piece materials for identifying the intensity of reactions taking place during process, analyze the influence of process parameters on the relative emission (i.e. ratio of emission rate to the material removal rate) using the Taguchi methodology of Experimental Design for suggesting suitable process conditions for green manufacturing.

2. Materials and methods

Experiments were conducted using the conventional die sinking electric discharge machine manufactured by Victory Electromech, Pune, India. Since majority of EDM operations include drilling holes of various shapes, a blind hole of 25 mm diameter was drilled on work pieces of 40 mm × 40 mm × 15 mm size. Copper was used as the tool