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

Study of thermal stresses induced surface damage under growing plasma channel in electro-discharge machining

*Panda Deepak Kumar**

Defence R&D Organization, Government of India, Institute of Technology Management, Landour Cantt., Mussoorie (UK) 248179, India

ARTICLE INFO

Article history:
Received 28 September 2006
Received in revised form
10 September 2007
Accepted 11 September 2007

Keywords:
EDM
Temperature distribution
Thermal stresses
Micro-crack
Thermally damaged layer

ABSTRACT

Steep temperature gradient induces thermal stresses, which can cause a network of micro-cracks, damaging the electro-discharge machined surface. In this context, review of different models reveals few limitations concerning too many assumptions and too simplified boundary conditions. Considering the limitations of the earlier models, the close form solution of three-dimensional heat conduction transient is used as forcing function to obtain the mathematical expression of thermal stresses. The temperature distribution function is obtained considering electro-discharged machine surface, which is both axially and radially infinite. Spatial and chronological variation of the heat source has been considered in undertaking a parametric study to characterize the thermal stress distribution. The study reveals that the induced thermal stresses exceed the ultimate stress of the material beyond the crater, which is the most crack prone. From the nature and the magnitude of thermal stresses, it is concluded that crack is initiated from the top edge of the crater and propagates towards the bottom of the crater, which is further corroborated from the photograph of the crater at suitable magnification.

© 2007 Elsevier B.V. All rights reserved.

1. Introduction

Electro-discharge machining (EDM) is primarily used in machining non-conventional materials of high strength, high strength-temperature resistant (HSTR) alloys widely used in the aeronautical and automotive industries (Die Sinking Technology, 2000; Srinivasulu et al., 2003). In this context, the post-machining surface integrity of work-materials is of prime concern.

Electro-discharge machining (EDM) is a thermal process where thermal energy is generated in a discharge channel, called plasma channel. Heat generated in the plasma channel in each spark, causes the work-material to melt (Mirnoff, 1965; Crookall and Heuvelman, 1977). Extremely high temperature resulted (Das et al., 2003; Ekmekci et al., 2005a,b) due to transient heat flux, induces thermal stresses within the heat-affected zone, which is the most potential zone of initiation of network of micro-cracks. Microscopic studies reveal multi-layered heat-affected zone including a hardened layer that possesses high brittleness, and reduced fatigue strength of the work-material (Das et al., 2003; Ekmekci et al., 2005a,b; Kruth et al., 1995; Rajurkar and Pandit, 1984; Yadav et al., 2002). Therefore, the electro-discharge machined surface is subjected to post-EDM processes such as grinding and polishing (Ramasawmy and Blunt, 2002) to remove these sub-surface defects. These post-machining treatments significantly contribute to the rising machining cost and are time consuming. In this context, computation of temperature and thermal stress profiles in the workpiece are of considerable interest to study the thermal stress-induced surface damage resulted in

* Tel.: +91 135 2635510; fax: +91 135 2632279.
E-mail address: pkdeepak@yahoo.co.uk.

0924-0136/$ – see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.jmatprotec.2007.09.040

Nomenclature

a	plasma channel radius (μm)
c	specific heat (J/kg °C)
C_r	crater radius (μm)
E	Young modulus (N/μm^2)
ierfc	repeated integral of complementary error function
I	spark current (A)
J_0	Bessel function of order zero
J_1	Bessel function of order one
k	thermal conductivity (J/m °C s)
Q_f	heat flux (J/m^2 s)
r	radial distance (μm)
R	radius of the semi-infinite solid workpiece (μm)
t	pulse duration (μs)
T_m	melting temperature of the electrode material (°C)
$T_{(r,z,t)}$	temperature distribution function (°C)
U	voltage across spark gap (V)
z	depth, along axial direction of three-dimensional solid cylinder (μm)

Greek symbols

α	thermal diffusivity ($k/\rho c$) (m^2/s)
ν	Poission ratio
ρ	density (kg/m^3)
σ_r	radial stress component (N/μm^2)
σ_z	axial stress component (N/μm^2)
σ_θ	tangential stress component (N/μm^2)
ψ	stress function
ω	co-efficient of thermal expansion (°C^{-1})

electro-discharge machining (Rajurkar and Pandit, 1984; Yadav et al., 2002).

In this paper, a mathematical model has been developed to compute thermal stresses by using temperature distribution function as forcing function. The temperature distribution function is obtained by solving a three-dimensional transient heat conduction equation considering uniform flux over the radial surface of a large size solid cylinder. A parametric study has been undertaken to characterize the thermal stress distribution so as to ascertain the role of these stresses in yielding damaged surface under a spark.

2. Thermal stress model

Extreme temperature gradient that result in EDM causes non-uniform local expansion. High thermal stresses are induced due to local expansion of the work-material being restrained (Rajurkar and Pandit, 1984; Yadav et al., 2002). The thermal stress can be built up to such a magnitude that it can exceed the fracture limit of the material. There are experimental evidences that the direction of propagation of cracks closely follows the profiles of the iso-thermals (Rajurkar and Pandit, 1984). This substantiates the rationale behind thermal stress-induced surface damage. So, it becomes a pre-requisite to study the stress profile developed due to transient temperature developed in the workpiece during EDM. In the present model, following assumptions are considered in developing theoretical expressions of thermal stress components:

(1) The effect of inertial and coupling is neglected. Thus the problem is quasi-static.
(2) Because of micron order of inter-electrode gap, both the electrodes constitute an infinite medium.
(3) Initially, the medium is stress free.
(4) The effect of creep on stress distribution is neglected due to the transient nature.

The stress–strain relations, in terms of cylindrical co-ordinates, are (Boley and Weiner, 1960; Timoshenko and Goodier, 1970)

$$\varepsilon_r = \frac{1}{E}[\sigma_r - \nu(\sigma_\theta + \sigma_z)] + \omega T \tag{1}$$

$$\varepsilon_\theta = \frac{1}{E}[\sigma_\theta - \nu(\sigma_r + \sigma_z)] + \omega T \tag{2}$$

$$\varepsilon_z = \frac{1}{E}[\sigma_z - \nu(\sigma_r + \sigma_z)] + \omega T \tag{3}$$

and, further, the stress function can be defined as

$$\sigma_r = \frac{\psi}{r} \tag{4}$$

$$\sigma_\theta = \frac{d\psi}{dr} \tag{5}$$

The compatibility equation for the rotationally symmetric case is

$$r\left(\frac{d\varepsilon_\theta}{dr}\right) + \varepsilon_\theta - \varepsilon_r = 0 \tag{6}$$

Substituting Eqs. (1), (2), (4) and (5) in Eq. (6) it becomes

$$\frac{d^2\psi}{dr^2} + \frac{1}{r}\left(\frac{d\psi}{dr}\right) - \frac{\psi}{r^2} = (-1)\frac{\omega E}{(1-\nu)}\frac{dT}{dr} \tag{7}$$

where $T = f(r, z, t)$.

The temperature distribution function (T), the solution of the transient heat conduction equation, is coupled with Eq. (7) as forcing function. The realistic estimation of temperature distribution function holds the key in obtaining realistic stress profile.

2.1. *Transient temperature distribution function (T)*

In order to determine the temperature distribution function due to a single spark, thermal models are developed by solving the following transient heat conduction equation in cylindrical co-ordinate.

$$\frac{\partial T}{\partial t} = \alpha\left[\frac{\partial^2 T}{\partial z^2} + \frac{\partial^2 T}{\partial r^2} + \left(\frac{1}{r}\right)\frac{\partial T}{\partial r}\right] \tag{8}$$

where $T = f(r, z, t)$.

Download English Version:

https://daneshyari.com/en/article/795418

Download Persian Version:

https://daneshyari.com/article/795418

Daneshyari.com