RESIDUAL STRESS MODELING AND ANALYSIS IN AISI A2 STEEL PROCESSED BY AN ELECTRICAL DISCHARGE MACHINE

MODELIRANJE ZAOSTALIH NAPETOSTI IN ANALIZA JEKLA VRSTE AISI A2, OBDELANEGA S POTOPNO EROZIJO

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Due to the creation of a significant temperature gradient, electrical discharge machining (EDM) causes localized, high thermal stress in a tiny heat-affected zone. This thermally developed stress leads to fatigue life and strength decrement, micro-cracks and probably catastrophic failure. On AISI A2 steel, a mathematical model based on finite-element analysis was constructed to estimate the temperature field and associated thermal stresses. In this present research work, the heat-flux distribution in a single spark during EDM is considered to be Gaussian distributed. The model first calculates the temperature distribution, and then uses this temperature field to determine the thermal stresses. It was observed that the stresses surpass the workpiece material’s yield strength near the center of the spark and this gradually weakens as the distance from the center increases.

Keywords: electrical discharge machining, numerical simulation, residual stress, AISI A2 die steel, Gaussian distribution, heat flux

1 INTRODUCTION

Electrical discharge machining (EDM) is a thermal machining process in which the discharge channel creates thermal energy. The resulting thermal energy in the discharge channel causes melting of the work piece and evaporation thereafter. Thermal energy discharge with a high density results in high temperatures being generated, which leads to thermal erosion and micro-cracks on the recast layer of the workpiece surface. The formation of the heat-affected zone in multi-layered recast layer and hardened surface brittleness leads to a fatigue-strength reduction of the work piece.1–3 So it is wiser to calculate the temperature distribution and then the thermal stresses in the work piece.

Klink et al. investigated the residual stress distribution on a wire-EDM-machined subsurface of ASP 23 tool steel. They found a high tensile residual stress zone about 30 mm beneath the material’s surface.4 In the wire-EDM of Ni and Ti alloys, Atar et al. reported a similar pattern.5 Wire-EDMed Udiment 720 components exhibited a much higher tensile residual stress on the surface and a short fatigue life, whereas milled parts had surface compressive stresses and a substantially longer fatigue life.6

Erden et al. gives a broad review of EDM mathematical models, which are based on a crater-formation phenomenon with a single spark. Wider and larger efforts are made so far for the estimation of the machined surface profile, crater volume, tool wear rate (TWR) and material removal rate (MRR). But the models that are useful to estimate the machined component’s surface integrity are still scarce.7 The surface-integrity models are
primarily based on a metallurgical analysis of EDM surfaces utilizing various experimental techniques such as scanning electron microscopy (SEM), optical metallography, and X-ray diffraction. Kruth et al. found that the electrical and work-piece materials, as well as the kind of dielectric, had an effect on the metallographic phase of the white layer. A review of the available literature reveals that there are very few theoretical techniques for determining the thermal stress.

The thermal energy generated in the EDM process influences the surface integrity of the machined work piece. So, it is very important to compute the temperature and thermal stress distribution in the machined components. In this context, firstly the temperature distribution in the machined component is computed and analyzed, and then the thermal stress due to a non-uniform distribution of temperature is estimated and the machined component is analyzed to determine the thermal residual stresses. The thermal residual stresses directly influence the surface quality.

There is a large literature on the thermo-mathematical modelling of the EDM process, which describes an excellent correlation with experimental results.

In the present work, the finite-element technique is used to model the thermal stress due to EDM. The designed model is to predict the thermal stress that will occur. To find out the developed thermal stress in the machined component during EDM, firstly the temperature distribution is calculated and then uses this temperature field to determine the thermal stresses. The temperature field is calculated using a temperature model that considers the heat flow magnitude and distribution.

2 MODELING

In EDM, the tool and workpiece are completely submerged and maintained at a gap, known as the inter-electrode gap in dielectric solution. Due to the complexity of the EDM process the following assumptions are made:

1) The workpiece material is isotropic and homogeneous.
2) About r-z plane, the domain is axisymmetric.
3) The properties of the workpiece material are independent of the temperature.
4) The heat transfer is carried out by convection process.
5) The analysis is made only for one spark.
6) The workpiece is stress free before the EDM process.
7) During a phase change the latent heat of the material is not considered.
8) Body force effects and inertia are negligible during the process of stress development.
9) Thermal stress is only analyzed up to the time when the transient temperature distribution above dielectric temperature is known.

10) The workpiece material is elastic-perfectly plastic, with a yield strength in tension equal to that in compression.

2.1 Modeling of temperature

2.1.1 Governing equations

In an axisymmetric domain, the single spark heating of a workpiece is considered. So, the heating of the workpiece is governed by the thermal diffusion differential Equation (1):

\[ \rho C \frac{\partial T}{\partial t} = \frac{1}{r} \frac{\partial}{\partial r} \left( k \frac{\partial T}{\partial r} \right) + \frac{\partial}{\partial z} \left( k \frac{\partial T}{\partial z} \right) \]

where \( \rho \) is density, \( C \) is specific heat capacity in the solid state of the workpiece, \( T \) is temperature, \( t \) is time, \( k \) is thermal conductivity, \( r \) and \( z \) are cylindrical coordinates.

2.1.2 Boundary conditions

For spark domain, a cylindrical small portion of the workpiece is considered. Heat input from a single spark serves to maintain the condition of a thermal boundary over the uppermost surface \( \Gamma_i \). The heat transmitted by the coolant on the upper layer \( \Gamma_i \) is modeled as a convective boundary condition. The boundaries \( \Gamma_2, \Gamma_3 \) and \( \Gamma_4 \) are so far apart that no heat transmission occurs across them. The boundary \( \Gamma_4 \) is a symmetric axis. As a result, the boundary conditions are as follows:

\[ k \frac{\partial T}{\partial r} = \begin{cases} h(T - T_0) & \text{if } r > R \\ q & \text{if } r \leq R \text{ on } \Gamma_i \\ 0 & \text{for off time} \end{cases} \]

For \( \Gamma_2, \Gamma_3 \), and \( \Gamma_4 \), \( \partial T / \partial n = 0 \)

where \( q \) is the entering heat flux inflowing inside the workpiece, the heat-transfer coefficient is denoted by \( h \), \( R \) is the spark radius, \( T_0 \) is the room temperature and \( n \) is the normal to the boundary.

Figure 1: Thermal model of EDM
The spark radius is determined by the electrical load, and measuring spark radius is challenging due to the extremely high pulse frequency. Shankar et al. used an integrated approach model to determine the spark shape to be non-cylindrical.13 Most researchers proposed empirical formula for calculating the spark radius.14–17 As per a literature review, there is a shortage of thorough information for evaluating its size and shape. The spark radius in this study was computed using Shankar et al.’s result as

\[ R = Z P^m T^n \]  \hspace{1cm} (4)

\( P \) denotes discharge power, \( T \) denotes time, while \( Z, m, \) and \( n \) denote empirical constants.

For the current workpiece material and the dielectric combination under consideration, it is recommended that, because power is a function of \( I_v \), the radius of spark can be calculated by altering Equation (3).

\[ R = Z I_p^n T_m^n \]  \hspace{1cm} (5)

where \( I_p \) is the discharge current, \( T_m \) is the pulse time on and the empirical constants \( Z = 325, m = 0.55, \) and \( n = 0.247 \) are used, and the spark radius can be written as:

\[ R = 325 I_p^{0.55} T_m^{0.247} \]  \hspace{1cm} (6)

### 2.1.4 Heat flux by a single spark

The shape of the crater produced during EDM suggested a non-uniform dispersion of a spark’s heat source. In the present paper, a Gaussian heat-flux distribution is assumed.18,19 The heat flux \( q_w \) at radius \( r \) is presented in Equation (7).

\[ q_w(r) = q_0 \exp \left\{ -4.5 \left( \frac{r}{R} \right)^2 \right\} \]  \hspace{1cm} (7)

The maximum intensity \( q_c \) at the spark axis and its radius \( R \) are known.

If one spark used the total power of each pulse then

\[ q_w(r) = \frac{4.45 R_v U_b I}{\pi R^2} \exp \left\{ -4.5 \left( \frac{r}{R} \right)^2 \right\} \]  \hspace{1cm} (8)

where \( U_b \) is the discharge voltage or breakdown voltage, \( R_v \) is the energy partition to the work piece and \( I \) is the current.

### 2.1.5 Energy partition \( R_w \)

The energy partition \( R_w \) is the proportion of the distributed input heat spread across the anode, cathode, and dielectric. It is determined by the material characteristics of the individual electrodes. Many researchers proposed values of energy partition \( R_w \) during EDM process, but no thorough technique for calculating the value of the energy partition \( R_w \) has been discovered yet during the EDM process. In this work the energy partition \( R_w \) is set at 0.08,20,21

### 2.2 Modeling of thermal stress

The thermal stresses in the workpiece are generated by an extreme temperature gradient during the EDM process. The transient distribution of temperature in the work piece, as well as the boundary and initial conditions, are used to calculate the thermal stresses.

#### 2.2.1 Equilibrium equations

In elasticity theory, the equilibrium equations must be satisfied by the stresses in the structure. The force equilibrium of a point is used to generate these Equations (9) and Equation (10).

\[ \frac{\partial \sigma_{rr}}{\partial r} + \frac{\partial \sigma_{rz}}{\partial z} + \frac{\sigma_{rr} - \sigma_{zz}}{r} = 0 \]  \hspace{1cm} (9)

\[ \frac{\partial \sigma_{rz}}{\partial r} + \frac{\partial \sigma_{zz}}{\partial z} + \frac{\sigma_{rr}}{r} = 0 \]  \hspace{1cm} (10)

where \( \sigma_{rr} \) is the shear stress and \( \sigma_{rr}, \sigma_{zz}, \) and \( \sigma_{00} \) are the normal stresses.

#### 2.2.2 Stress–strain–temperature relations

Because of the temperature rise \( \Delta T \), the stress-strain-temperature relationship is

\[ \{ \sigma \} = \{ E \} \{ \varepsilon \} - \{ m \} \]  \hspace{1cm} (11)

where \( \{ \sigma \} \) is the stress vector, \( \{ \varepsilon \} \) is the strain vector and \( \{ E \} \) is the elasticity matrix.

\[ \{ \sigma \}^T = \{ \sigma_{rr}, \sigma_{rz}, \sigma_{00}, \sigma_{zz} \} \]  \hspace{1cm} (12)

\[ \{ \varepsilon \}^T = \{ \varepsilon_{rr}, \varepsilon_{rz}, \varepsilon_{00}, \varepsilon_{zz} \} \]  \hspace{1cm} (13)

\[ \{ m \} = \begin{bmatrix} 1 & E \alpha \Delta T \\ 1 & 1 - 2\nu \\ 0 & 0 \\ 0 & 1 - 2\nu \end{bmatrix} \]  \hspace{1cm} (14)

where \( \alpha \) is the coefficient of thermal expansion, \( E \) is the Young’s modulus and \( \nu \) is the Poisson’s ratio.

\[ \{ m \} = \frac{E}{(1+\nu)(1-2\nu)} \begin{bmatrix} 1-\nu & \nu & \nu & 0 \\ \nu & 1-\nu & \nu & 0 \\ \nu & \nu & 1-\nu & 0 \\ 0 & 0 & 0 & \frac{1-2\nu}{2} \end{bmatrix} \]  \hspace{1cm} (15)

Because of the temperature rise \( \Delta T \), the final stress-strain-temperature relationship can be represented as

\[ \begin{bmatrix} \sigma_{rr} \\ \sigma_{00} \\ \sigma_{rz} \\ \sigma_{zz} \end{bmatrix} = \begin{bmatrix} \sigma_{rr} \\ \sigma_{00} \\ \sigma_{rz} \\ \sigma_{zz} \end{bmatrix} \frac{E}{(1+\nu)(1-2\nu)} \begin{bmatrix} 1-\nu & \nu & \nu & 0 \\ \nu & 1-\nu & \nu & 0 \\ \nu & \nu & 1-\nu & 0 \\ 0 & 0 & 0 & \frac{1-2\nu}{2} \end{bmatrix} \]  \hspace{1cm} (16)
2.2.3 Strain displacement relations

\[ \varepsilon_{rr} = \frac{\partial u}{\partial r}, \quad \varepsilon_{zz} = \frac{\partial w}{\partial z}, \quad \varepsilon_{\theta\theta} = \frac{u}{r}, \quad \varepsilon_{rz} = \frac{\partial u}{\partial z} + \frac{\partial w}{\partial r} \]  

(17)

where \( u \) and \( w \) are the displacements, \( \varepsilon_{rr}, \varepsilon_{zz}, \) and \( \varepsilon_{\theta\theta} \) are the normal strains, and \( \varepsilon_{rz} \) is the shear strain.

2.2.4 Plastic zone

The equivalent thermal stress in the plastic zone is larger than the yield strength of the material and this point is recognized by the inequality as:

\[ \sigma_{eq} \geq \sigma_y \]  

(18)

The deviatoric stress components are:

\[ S_{rr} = \sigma_{rr} - \frac{1}{3}(\sigma_{rr} + \sigma_{zz} + \sigma_{\theta\theta}) \]  

(19)

\[ S_{\theta\theta} = \sigma_{\theta\theta} - \frac{1}{3}(\sigma_{rr} + \sigma_{zz} + \sigma_{\theta\theta}) \]  

(20)

\[ S_{zz} = \sigma_{zz} - \frac{1}{3}(\sigma_{rr} + \sigma_{zz} + \sigma_{\theta\theta}) \]  

(21)

The effective or equivalent stress is:

\[ S_{eq} = \sqrt{3J_2} \]  

(22)

where \( J_2 \) is:

\[ J_2 = \frac{1}{2}(S_{rr}^2 + S_{zz}^2 + S_{\theta\theta}^2) + S_{rz}^2 \]  

(23)

2.2.5 Boundary conditions

In Figure 1 the displacement \( u \) and \( w \) along and across the surface \( \Gamma_4 \) are supposed to be zero.

\[ u = 0 \quad \text{and} \quad w = 0 \quad \text{on} \quad \Gamma_4 \]  

(24)

Because the surface \( \Gamma_4 \) has an axis of symmetry, the shear component of the traction vector \( t_s \) and the normal component of the displacement vector \( u \) are both zero along the boundary.

\[ t_s = 0 \quad \text{and} \quad u = 0 \quad \text{on} \quad \Gamma_4 \]  

(25)

Because surface \( \Gamma_2 \) is far away from the heat source, it is deemed to be stress-free. Thus, the traction components \( t_t \) and \( t_r \) are zero along the surface \( \Gamma_2 \).

\[ t_t = 0 \quad \text{and} \quad t_r = 0 \quad \text{on} \quad \Gamma_2 \]  

(26)

Because the surface \( \Gamma_1 \) is a free surface, the traction components \( t_t \) and \( t_r \) are both zero along the surface \( \Gamma_1 \).

\[ t_t = 0 \quad \text{and} \quad t_r = 0 \quad \text{on} \quad \Gamma_1 \]  

(27)

The stress tensor \( \sigma_{ij} \) and the traction component \( t_i \) and \( t_s \) are related as

\[ t_i = \sigma_{ij} n_j \]  

(28)

The components of the unit outward normal vector are denoted by \( n_i \).

3 FINITE-ELEMENT ANALYSIS

The temperature and thermal stress distributions due to a single spark’s heat flux are calculated using a Galerkin finite-element approach.

3.1 Temperature analysis

When the Galerkin technique is used on the EDM process then the elemental capacitance matrix \([C]_i\) is

\[ [C]_i = \int \int \rho C \{N^e\}^t \{N^e\} \, r \, d\tau \, dz \]  

(29)

Elemental conductivity matrix \([K]_i\) is

\[ [K]_i = \int \int \rho C [B^e]^t [B^e] \, r \, d\tau \, dz \]  

(30)

Boundary conductivity matrix

\[ [K_b] = \int \int r \{N^b\}^t [q^b] \, d\Gamma \]  

(31)

Boundary flux vector

\[ [f^b] = \int \int r \{N^b\}^t \{q^b\} \, d\Gamma \]  

(32)

where \( \{N^e\} \) denotes the shape-function vector for the elemental element and \( \{N^b\} \) denotes the shape function vector for the boundary element. \([B^e]\) is a matrix that displays derivatives of temperature with their nodal values. Where \( \Gamma_b \) is the boundary element domain, \( \Omega^e \) is the element area domain, and \( \{q^b\} \) is the vector that contains nodal values of the heat flux.

The preceding equations are numerically calculated using Gaussian quadrature, taking three points in each direction into account. When the elemental quantities of the preceding equations are added together, we get the differential equations shown below.

\[ [C]_i \{T\}_i + [K]_i \{T\}_i = \{F\}_i \]  

(33)

where \( \{T\}_i \) is the global temperature vector, \( \{T\} \) is the time derivative of \( \{T\}_i \), \( \{F\}_i \) is the global heat flux vector, \([C] \) is the global capacitance matrix and \([K] \) denotes the global conductivity matrix.

The above differential equations are solved by the finite-difference method. This technique transforms the differential equations listed above into a set of algebraic equations as

\[ [A]_{i+1} \{T\}_{i+1} = \{B\}_{i+1} \]  

(34)

where,

\[ [A]_{i+1} = [C] + \theta \Delta t_{i+1} [K] \]  

(35)

\[ [B]_{i+1} = \Delta t_{i+1} (\theta \{F\}_{i+1} + (1 - \theta) \{F\}_i) + (\{C\} - (1 - \theta) \Delta t_{i+1} [K]) \{T\}_i \]  

(36)

In present work \( \theta = 2/3 \) (Galerkin scheme).

The solution of the aforementioned simultaneous algebraic equations yields the nodal temperature at the new time level after each time interval \( \Delta t \). As a result, the solution follows the time as \( \Delta t_{i+1} \) equals the pulse on.

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time and $\Delta t$ equals the pulse off time of EDM until the required end time is reached.

### 3.2 Residual thermal stress evaluation and analysis

The equilibrium equations will not be fully satisfied by the displacement function. In the overall sense, a set of functions known as weighted functions ($w_1$ and $w_2$) are utilized to nullify the resulting error in them. Equilibrium equations with a weighted integral expression are expressed as

$$
\int_a^b \left[ \frac{\partial w_1}{\partial x} + \frac{\partial w_2}{\partial y} + \frac{\partial w_3}{\partial z} \right] \psi_1 + \psi_2 = 0
$$

Applying divergence theorem

$$
\int_{\Omega} \nabla \cdot [\{w\}] [\{\psi\}]^T 2\pi r dr dz
$$

Using the stress-strain-temperature relationship of Equation (11)

$$
\int_{\Omega} \nabla [\{w\}]^T [\{\psi\}] 2\pi r dr dz
$$

A parabolic curve defines the boundaries of isoperimetric elements, eight isoperimetric elements are used for the present analysis. The strain and displacement of each element are

$$
\{e\} = [B] \{\delta\}^e
$$

where $[N]$ denotes the shape-function matrix, while $[B]$ denotes the matrix containing derivatives of the shape function and $[\delta]^e$ denotes the nodal displacement vector.

The temperature increase within an element is represented as:

$$
\Delta T = \sum_{i=1}^{4} N_i \eta^i \psi^i - T_0
$$

We can also write:

$$
\{\nabla w\} = [B] \{w\}^e \text{ (Galerkin scheme)}
$$

where the elements’ nodal weights are denoted by $\{w\}^e$.

Substituting Equation (40) and Equation (43) in a weighted integral expression of equilibrium Equation (39):

$$
\sum_{i=1}^{4} \{w\}^e [STK]^e [\delta] = \sum_{i=1}^{4} \{w\}^e [stf]^e
$$

where $ne$ is the no. of area element, $[STK]^e$ is the elemental coefficient matrix for stress and $[stf]^e$ is the elemental force vector

$$
[stf]^e = \int [B]^e [\psi\eta] 2\pi r dr dz
$$

The Gauss quadrature integration technique $3 \times 3$ is applied to solve the above integrals Equation (45) and Equation (46). We can also write assembled finite elemental equations as

$$
[GF] [GU] = [GF]
$$

The global nodal displacement vector is denoted by $[GU]$, the global right-side vector by $[GF]$ and the global coefficient matrix by $[GF]$. The Gauss elimination method is applied to the aforementioned Equation (47) to calculate the nodal displacement after boundary conditions are applied.

The solution of Equation (47) is obtained in terms of nodal displacement. The thermal stress is calculated by nodal displacement and temperature distribution as input by Equation (11) and (40). Equation (22) is used to compute the equivalent stress, which is then compared to the yield stress to determine whether yielding occurs. The process of comparison is carried out for all the elements.

### 4 RESULT AND DISCUSSION

A FEM-based model was developed for the thermal stress analysis of the work piece in EDM. For validation, the temperature distribution of the present model is compared with numerical results of Yadav et al. and Shankar et al. having the same process conditions. In the present model, the temperature distribution is determined using a Gaussian heat-flux distribution with an energy partition $R_e$ value of 0.08. Different process parameters were used by researchers for thermo-mathematical modeling of EDM. The material properties and process parameters used in the present model are given in Table 1.

<table>
<thead>
<tr>
<th>Material</th>
<th>AISI A2 Die Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C/(J/kg)$</td>
<td>460.0</td>
</tr>
<tr>
<td>$E/(GN/m^2)$</td>
<td>190</td>
</tr>
<tr>
<td>$\kappa/(W/m^2K)$</td>
<td>10,500</td>
</tr>
<tr>
<td>$I/A$</td>
<td>9</td>
</tr>
<tr>
<td>$K/(W/mK)$</td>
<td>26</td>
</tr>
<tr>
<td>$R/\mu m$</td>
<td>125</td>
</tr>
<tr>
<td>$R_e$</td>
<td>0.08</td>
</tr>
<tr>
<td>$T_m/K$</td>
<td>1697</td>
</tr>
<tr>
<td>$T_y/K$</td>
<td>298</td>
</tr>
<tr>
<td>$U/o(V)$</td>
<td>40</td>
</tr>
<tr>
<td>$\rho/(kg/m^3)$</td>
<td>7750</td>
</tr>
</tbody>
</table>

Figure 2 shows the variation of the top surface temperature distribution for the Gaussian heat source along the radial direction from the center. The temperature profile along the radial axis is parabolic in nature.

The comparison of the temperature distribution with the result of Yadav et al. and Shankar et al. is shown in
Outside the spark radius, there is substantial agreement. One of the reasons for the quantitative discrepancy in the spark radius zone is a variation in the heat-flux profiles adopted. The Gaussian heat source, which is considered to be more realistic, exhibits severe temperature gradients inside the spark radius region. These steep gradients are found to be the major cause of thermal stresses in the workpiece.

The thermal stress components are calculated for each of the Gaussian integrating points within each discretized domain element. All Gauss points at the top surface of the considered domain and element size are discovered to be 7 μm, well below the top layer of the domain. Likewise, all Gauss points near the center line of the spark are discovered to be 7 μm far from the center line. As a result, typical planes near the spark are selected to show the results of stress distributions along the radial distance and depth for simulation results.

Figure 4 and Figure 6 show that the variation of the thermal stresses component along the radial distance in AISI A2 die steel workpiece at 7 μm below the top surface. Because of the constraint from the material that expands less, a compressive stress area is detected around the spark center point \( r = 0 \). A section of the workpiece material under a spark expands more considerably owing to the higher temperature rise, causing compressive stresses. The radial component \( \sigma_{rr} \) is found to be the highest with an approximate value of 2700 MPa, closely followed by the tangential component \( \sigma_{t\varphi} \) with approximate value of 2650 MPa, followed by an axial/vertical component \( \sigma_{zz} \) is only about 700 MPa. The shear component \( \sigma_{r\varphi} = 150 \) MPa is substantially less than the other three components \( \sigma_{rr}, \sigma_{tt}, \sigma_{t\varphi} \) and its sign shifts somewhat away from the spark’s center. Beyond 400 μm from the center, almost no thermal stresses are found.

Figure 5 and Figure 7 show the variation of the thermal stresses’ component down the depth in an AISI A2 die steel workpiece about 7 μm below the top surface. In almost all cases, the stress fields are tensile in nature. These curves also illustrate that the undesirable thermal tensile stresses are critical near the top surface. They
**Figure 6:** Variation along radial distance; a) radial component of thermal stress ($\sigma_r$), b) tangential component of stress ($\sigma_\theta$), c) axial/vertical component of stress ($\sigma_z$), d) shear component of stress ($\sigma_{rz}$)

**Figure 7:** Variation along radial distance; a) radial component of thermal stress ($\sigma_r$), b) tangential component of stress ($\sigma_\theta$), c) axial/vertical component of stress ($\sigma_z$), d) shear component of stress ($\sigma_{rz}$)
fluctuate up to 100 μm, but slowly drop to zero beyond 300 μm. The most critical component is axial/vertical $\sigma_z$ that fluctuates within 100 μm depth from ~750 MPa to 1250 MPa. This demonstrates that $\sigma_z$ causes huge residual thermal stress close to the top surface.

5 CONCLUSION

In the present study, numerical simulations were carried out with a final element-based code for predicting the temperature distribution and thermal stress fields after a single spark of EDM in an AISI A2 steel workpiece. In developing the model, the important characteristics of the process are considered, for example, temperature-dependent material properties, the size and shape of heat source (Gaussian heat source), the percentage fraction of the heat input to the workpiece, the pulse time on/off. The temperature profile and thermal stress distribution around a single spark that occur in the work piece material as a result of high temperature, deformations, and transient operation are analyzed. The temperature rises sharply during the heating cycle and then drops rapidly during the quenching cycle. Thermal compressive stresses are observed beneath the crater, while tensile stresses appear away from the axis of symmetry. After one spark, significant compressive and tensile stresses are observed in a thin layer around the spark location. Thermal stresses are also observed to exceed the workpiece’s yield strength in a very thin area near the spark. The findings provided insight into the potentially hazardous nature of thermal stresses generated during EDM.

6 REFERENCES

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