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Finite Element Analysis of Temperature Distribution and Residual Stresses in Wire Electrical Discharge Machining Process

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Abstract

High temperature gradients resulting in the process of formation of the electrical discharge of electrical impulses lead to residual stresses in the surface layers of electrodes. This residual pressure can lead to deficiencies of the piece work piece as small cracks, low strength and fatigue life, and perhaps catastrophic failure. Wire electrical discharge machining (WEDM) is widely used in machining of conductive materials when precision is considered as a prime importance. In this work proposes a 3D finite element model by using ANSYS software and statically approach to predict temperature distribution at different pulse time as well as stress distribution in wire of wire electrical machining. A transient thermal analysis assuming a Gaussian distribution heat source with temperature-dependent material properties has been used to investigate the temperature distribution and stress distribution. Thermal stress developed after the end of the spark and residual stress developed after subsequent cooling. The effect of parameter pulse- on -time on machining has been investigated and found that peak temperature is sharply increases with pulse-on-time.

Keywords: WEDM, ANSYS, EDM, 3D finite element,

Introduction

Electric Discharge Machining (EDM) provides an effective manufacturing technique that enables the production of parts made of hard materials with complicated geometry that are difficult to produce by conventional machining processes. Its ability to control the process parameters to achieve the required dimensional accuracy and finish has placed this machining operation in a prominent position in industrial applications. The absorbing interest for electric discharge machines has resulted in great improvements in its technology.

A. Wire-EDM

Wire electrical discharge machining process is a mostly used non-conventional material removal processes. This is use for manufacturing difficult shape and profile of hard materials. This is considering as a distinctive variation of the conventional electrical discharge machining processes. The wire does not touch the work piece,so there is no physical pressure imparted on the work piece compared to grinding wheels and milling cutters. The amount of clamping pressure required to hold small, thin and fragile parts is minimal, preventing damage or distortion to the work piece.In the WEDM, demand is growing for high rate cutting speed and high accuracy machining for improve the productivity of product and also for achieve high Accuracy and precise quality of job with and Excellence quality in machining job. In wire electrical discharge machining process a always travelling wire electrode made of thin copper, brass or tungsten of diameter 0.05–0.3 mm is used, which is precisely controlled by a CNC system. Here role of CNC is very important. The function of CNC is unwind the wire from first spool, and feed throughout the work-piece, and takes it on a second spool. Generally wire velocity varies from 0.1 to 10 m/min, and feed rate is 2 to 6 mm/min. A direct current is used for generate high frequency pulse to the wire and the work piece. The wire (electrode) is hold in tensioning device for decreases the chance of producing inaccurate parts. In wire electrical machining process, the work piece and tool is eroded and there is no direct contact between the work piece and the electrode, and this reduces the stress during machining. WEDM was originally developed by 1960. The manufacturing industry technical development of machining electrode used in the electric discharge machining is replaced. In 1974, D. H. Dulebohn brought on line optical tracking system, which is the automatic control of the shapes of the part by the electric discharge machining process thread. In 1975, he was popular quickly, and its capacity is better understood by the manufacture. When the numerical control WEDM process by the computer system was introduced into this caused a further development of the machining process. Accordingly, the electric discharge machining wire large processing capacity has been widely exploited for all machining through the hole because of the wire which has to pass through the room. The common EDM wire process application is the manufacture of stamping and extrusion tools and dies, fixtures and gauges, prototypes, aircraft and medical parts and grinding and the shape of the wheel. formed next to the previous ones and the work piece surface is constantly eroded.

B. Wire electrical discharge machining process

Wire electrical discharge machining (EDM) is a non-traditional machining process that uses electricity to cut any conductive material precisely and accurately with a thin, electrically charged copper or brass wire as an electrode. During the wire EDM process, the wire carries one side of an electrical charge and the work piece carries the other side of the charge. When the wire gets close to the part, the attraction of electrical charges creates a controlled spark, melting and vaporizing microscopic particles of material. The spark also removes a miniscule chunk of the wire, so after the wire travels through the work piece one time, the machine discards the used wire and automatically advances new wire. The process takes place quickly—hundreds of thousands of sparks per second—but the wire never touches the work piece. The spark erosion occurs along the entire length of the wire adjacent to the work piece, so the result is a part with an excellent surface finish and no burrs regardless of how large or small the cut.

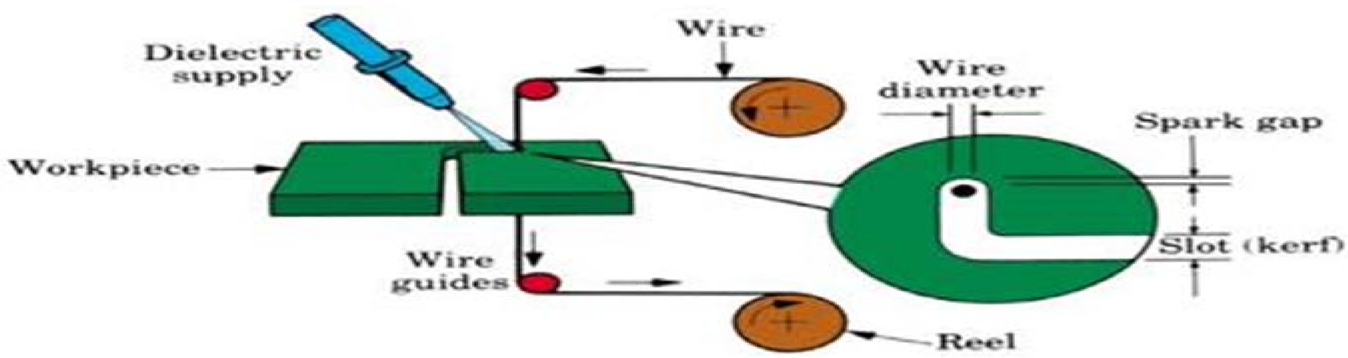


Fig. 1: Wire electrical discharge machining process

C. Principle of spark erosion

The principle of spark erosion is simple. The work piece and tool are placed such a way that these don't touch each other. These are separate through a gap which is filling with dielectric fluid. The cutting mechanism therefore takes place in a container. The work piece and tool are connected to a direct current source. There is a switch in one lead. When this is closed, an electrical potential is applied between the work piece and tool. At initially no current flows since the dielectric between the work piece and tool is an insulator. If gap is decreases then a spark jumps across it when it reaches a certain very small size. In this process, current is converted into heat and form plasma channel. Surface of the materials is very powerfully heated in the area of the discharge channel. If the flow of current is sporadic the discharge channel collapses very quickly. Therefore the molten metal on the surface of the material evaporated explosively and takes liquid material with it down to a certain depth. A small crater is formed. If one discharge is followed by another, new craters are

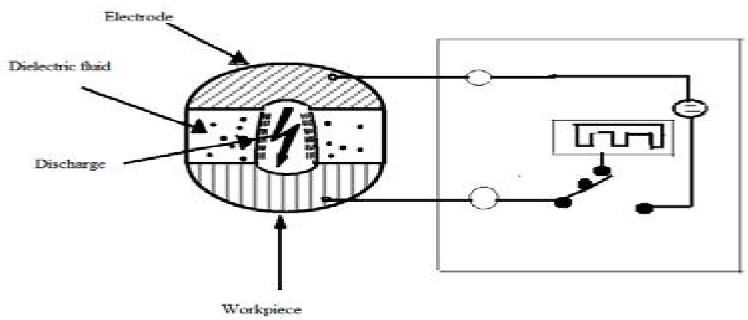


Fig. 2: Sparking phenomena in WEDM process

D. Residual Stresses

Residual stresses are self-equilibrating stresses existing in materials under uniform temperature conditions without external loading. Such stresses will be always produced if regions of a material are non-homogeneous plastically deformed in such a permanent manner that strain incompatibilities occur. Residual stresses can be classified in three categories according to the distance or range over where the stresses equilibrated. Residual stresses act in a body without applying forces or moments. Therefore the effect of residual stresses can be found by considering the material behaviour under real loading conditions. The main result of residual stresses on a mechanical component is the deformation due to the new state of equilibrium. In addition, for a material this has a characteristic yield point, the residual stresses act like a pre-stress state and changes the level of the yield strength.

Finally, the dynamic strength changes considerably. This can be explained as the change in mean residual stress level during cyclic loading.

Objective of the Present Work

- To determine the temperature distribution, displacement and stress distribution in wire Electrode tool of WEDM using FEM analysis.
- To develop a thermo-structural modelling of wire electrode tool for analyzing the effect of built-in temperature to the machining performance.

Design of Experiments

A. Modelling procedure using ANSYS of WEDM

In the wire EDM, a series of rapid electric spark occur in the gap between tool (wire) and work piece. Addition of particles into the dielectric fluid makes this process more complex and random. The following assumptions are made without sacrificing the basic features of the wire EDM model to make the problem mathematically feasible.

B. Thermal model of Wire EDM Assumptions

1. The model is developed for a single spark.
2. The thermal properties of work piece material are considered as a function of temperature. It is assumed that due to thermal expansion, density and element shape are not affected.
3. Temperature analysis is considered to be of transient type.
4. The material of the wire is homogeneous, isotropic and has constant properties.
5. The heat source is assumed to have Gaussian distribution of heat flux on the surface of the work piece.
6. The composition of the material of work piece is assumed to be homogeneous and isotropic.

C. Thermal Model

The discharge phenomenon in wire EDM can be modelled as the heating of the work piece by the incident plasma channel. The mode of heat transfer in solid is conduction.

$$\frac{\partial}{\partial r}\left(kw\frac{\partial T}{\partial r}\right)+\frac{1}{r^2}\frac{\partial}{\partial \theta}\left(kw\frac{\partial T}{\partial \theta}\right)+\frac{\partial}{\partial z}\left(kw\frac{\partial T}{\partial z}\right)+q''' = \rho c\frac{\partial T}{\partial t}$$

Where r and θ is the radial and angle coordinates respectively, z is the axial coordinate, and c are the density and the specific heat of the wire material, KW thermal conductivity of the wire material and T is the temperature of the micro element in the wire.

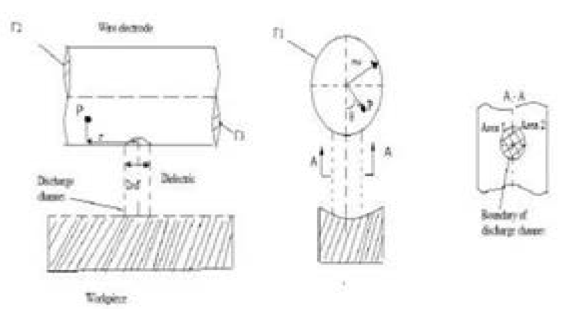


Fig.3: Three-dimensional thermal analysis model for WEDM

1. Boundary conditions

The boundary between area1 and area 2 can be mathematically determined by the following equations:

$r = r_w$

$$(r_w \sin\theta)^2 + z^2 = r_d^2$$

Where r_d is defined as the radius of the discharge channel, r_w is the wire radius, and Γ́1 represents the cylindrical boundary between the wire and the dielectric. From fig. 3 in inside area 2, the thermal equilibrium can be described as the following equations: Where, h is the heat transfer coefficient, T0 is the initial temperature of wire electrode and T Temperature.

2. Material properties

Brass wire the chemical composition of brass is 62% Cu and 38% Zn.

Table 1: Properties of brass wire Molybdenum wire

Properties	Unit	Value
Density	Kg/m^3	8490
Thermal conductivity	W/mK	115
Specific heat	J / kg K	380
Modulus of Elasticity	G Pa	97
Bulk Modulus	G Pa	140
Poisson's Ratio		.31
Melting temperature	0_C	1083
Shear Modulus	G Pa	37
Solidus	0_C	885

Table 2: Properties molybdenum wire

Properties	Unit	Value
Thermal Conductivity	W /m-k	139
Coefficient of linear thermal expansion	$_K$-1	-6
Density	kg /m^3	4.8 x 10
Young's modulus of elasticity	G Pa	10280
Poisson's ratio		329
Shear modulus	G Pa	.31
Melting point	0_C	126

3. Heat Flux due to the wire electrode in a single spark

In this paper, a Gaussian heat distribution is assumed. If it is assumed that total power of power of each pulse is to be used only single spark can be written as follows:

$$q(r) = \frac{k}{\pi R^2(t)} PVI \, exp.(-\frac{kr^2}{R^2(t)}$$

Where q(r) is the heat flux at the radius of r, k is the heat concentration coefficient (k=4.5, unieda et al. case), R (t) is the radius of arc plasma at the moment of t, P is the energy distribution coefficient (= 0.38, Kunieda et al.), V is the voltage between anode and cathode during discharge occur, I is the peak current and r is the distance from the centre of arc plasma.

Spark Radius

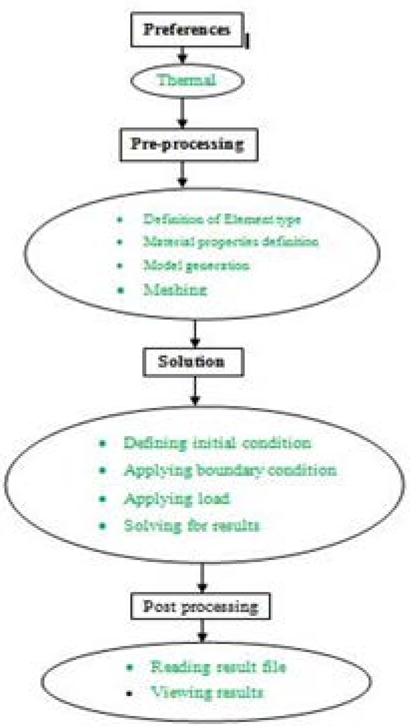
Spark radius is an important parameter in the thermal modelling of WEDM process. In practice, it is very difficult to measure experimentally, because spark radius very short pulse duration of in microseconds. Ikai and Hashiguch have derived a semi-empirical equation of spark radius termed as ``equivalent heat input radius" which is a function of discharge current, I (A) and discharge on- time, ton (μs). It is more realistic when compared with the other approaches.

$$\text{Spark radius}\,(R) = \left(2.04\,e^{-3}\right) I^{0.43}\, t_{on}^{0.44}\,) \quad (\mu m)$$

D. Finite Element Analysis Procedure using ANSYS software

Thermal analysis of brass wire

The general finite element modelling procedure consists of the following steps:



Process of thermo-structural modeling

a) 1. Open Mechanical APDL (ANSYS).

b) Go to File > Change Title and give a new title for the example.

c) Preferences

3. Pre-processing>element type> Add/Edit/Delete

a) Click on add

b) Select thermal solid on the left list and Brick 8 node 70 on right list(i.e. element type) click on OK

c) CLOSE

- Material properties>temperature unit>Celsius>ok
- Material Models>thermal >conductivity>isotropic>ok ,put value>density put value>specific heat put value>material exit
- Modelling>create>cylinder>sold cylinder>put the dimensions
- Meshing>mesh tool> smart size 6>mesh >ok

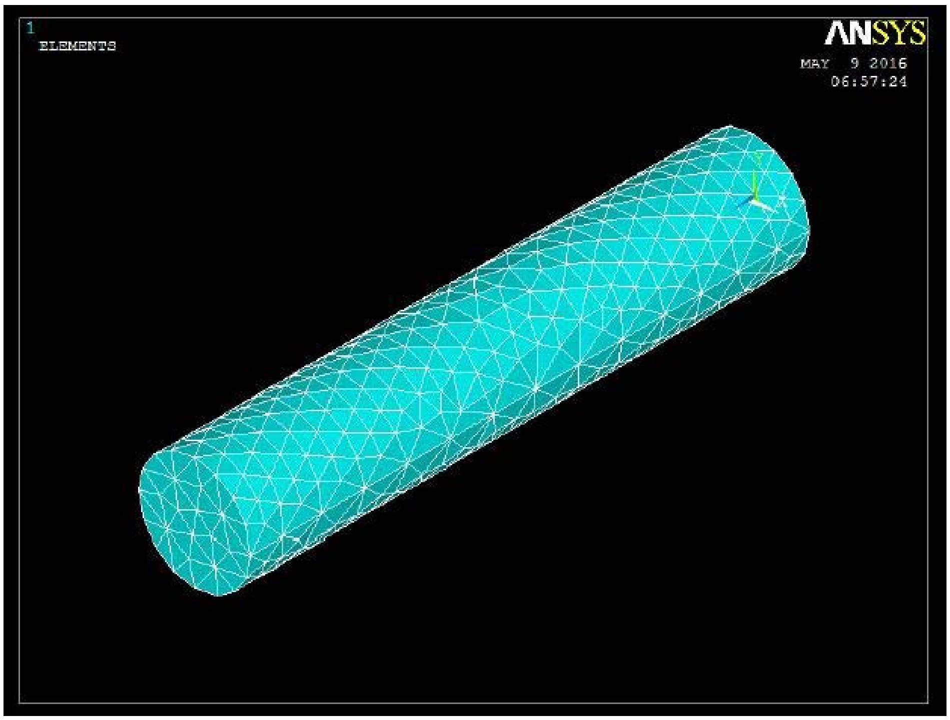


Fig. 4: Three-dimensional view of the meshed model

Results and Discussions

ANSYS model confirmation

- Thermal modelling of wire EDM for single spark in brass wire.
- Thermo-structural analysis of WEDM in brass wire.

Thermal modelling of wire EDM for single spark in brass wire

Table 3: Parameters used for thermal analysis in WEDM process

Parameter	Unit	Value
Peak current of electro-Discharge	A	29
Voltage of electro discharge,	V	26
Duration of single pulse	µs	0.11, 0.26, 0.36, 0.52, 0.58, 1.2, 1.82
Wire radius	mm	0.05
Convective coefficient	$W/m^{2\,o}C$	3040
Temperature of the dielectric	oC	21
Poisson' ratio		.31
Coefficient of linear thermal expansion	K^{-1}	1.9×10^-5

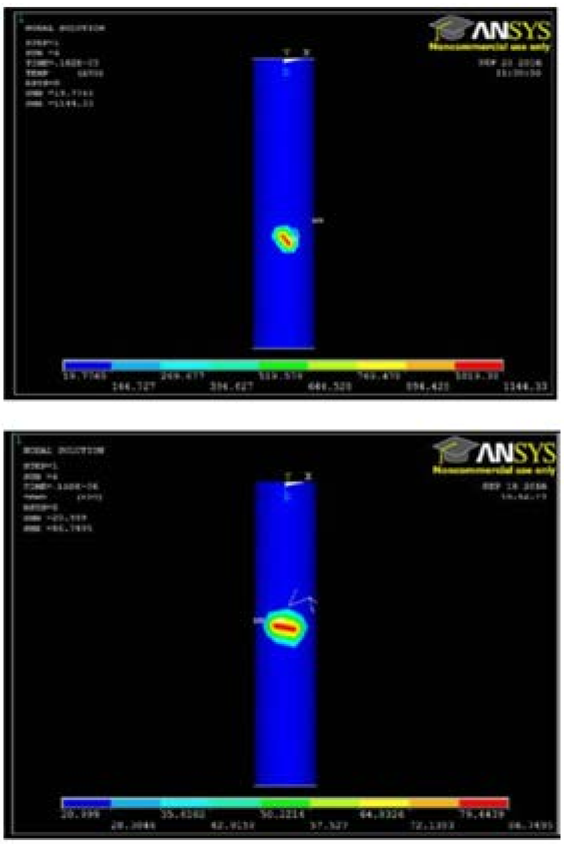


Fig. 5: Temp distribution in brass wire V=26, I=29, P=0.38, Ton=0.11µs

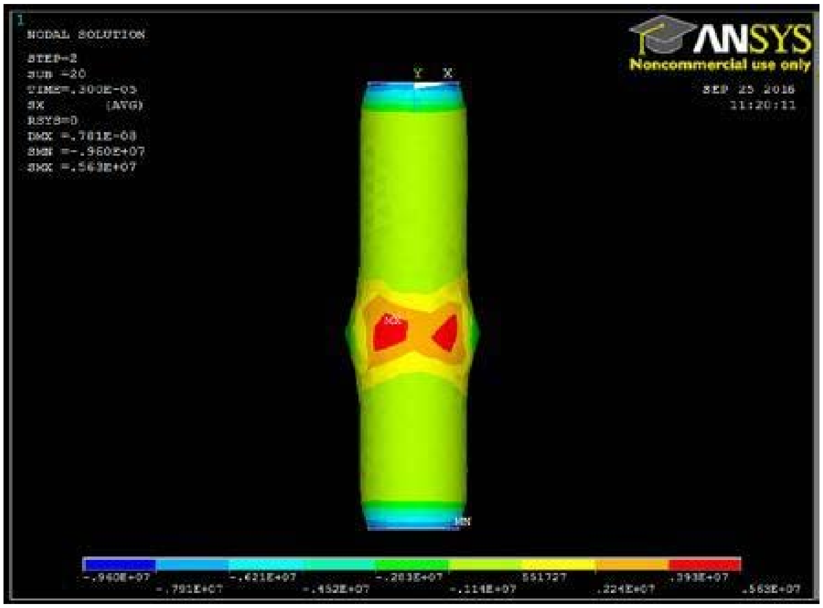
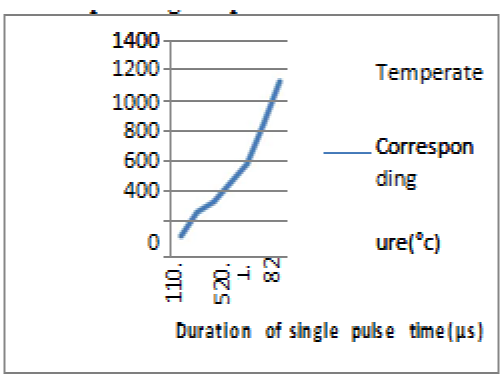


Fig. 6: Temp distribution in brass wire V=26, I=29, P=0.38, Ton=1.82

Observation of corresponding Temperature by varying Duration of single pulse

S.NO	Duration of single pulse(µs)	Corresponding temperature(^{0}c)
1.	0.11	86.7495
2.	0.26	247.699
3.	0.36	318.578
4.	0.52	446.967
5.	0.58	578.335
6.	1.2	854.831
7.	1.82	1144.33

Observation graph between duration of single pulse time and investigated corresponding temperature



Parameter	Units	Value
Radius of wire	Mm	0.125
Length of wire	M	0.1
Tension	N	13.7295
Initial temperature	K	273
Working temperature	K	390

Structural modelling of WEDM in molybdenum wire

Graph of displacement

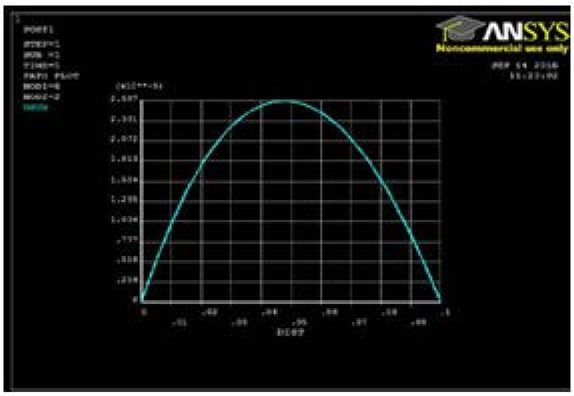


Fig: 7 Thermal Stress in X-component atton=0.11µsThermal and residual stress at Ton-0.11µs

Thermal and residual stress at Ton-0.52µs

Stress type	Value(Mpa)	Direction
σ thermal	148	X
σ thermal	188	Y
σ thermal	282	Z
σ thermal shear	134	XY
σ thermal shear	135	XZ
σ thermal shear	139	YZ
σ residual	289	YZ

Thermal and residual stress at Ton-1.82µs

Stress type	Value(Mpa)	Direction
σ thermal	277	X
σ thermal	157	Y
σ thermal	425	Z
σ thermal shear	180	XY
σ thermal shear	150	XZ
σ thermal shear	171	YZ
σ residual	533	

Conclusions

In this dissertation, a robust three dimensional finite element model has been developed using ANSYS software to predict the temperature distribution at different pulse time as well as stress distribution in the wire of WEDM. A transient thermal analysis assuming a Gaussian distribution heat source with temperature-dependent material properties has been used to investigate the temperature distribution and stress distribution. Thermal stress was developed after the end of the spark and also residual stress was developed after subsequent cooling. Finite element modeling was carried out for a single spark with temperature-dependent material properties. Certain parameters such as spark radius, discharge current and discharge duration, the latent heat, the plasmachannel radius and Gaussian distribution of heat flux, the percentage of discharge energy transferred to the tool electrode have made this study nearer to real process conditions. The FE model shows that, at pulse time = 0.11 µs, corresponding temperature is 86.750C and maximum residual stress is 778 Mpa. At pulse time = 0.26 µs, corresponding temperature is 247.70C and .At pulse time = 0.36 µs, corresponding temperature is 318.60C. At pulse time = 0.52 µs, corresponding temperature is 446.90C and the maximum compressive stress is 288Mpa in Z -component, and maximum residual stress is 288 Mpa. . At pulse time = 0.58 µs, corresponding temperature is 578.3350C. At pulse time = 1.2 µs, corresponding temperature is 854.80C. At pulse time = 1.82 µs, corresponding temperature is 11440C and the maximum compressive stress is 425Mpa for ton=1.82µs in Z-component, and maximum residual stress is 533 Mpa. Further increasing the pulse time is not possible because, at temperature 10830C, the brass wire melt.

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