NUMERICAL PREDICTION OF WELD BEAD GEOMETRY IN PLASMA ARC WELDING OF TITANIUM SHEETS USING COMSOL

V.DHINAKARAN
Research Scholar
National Institute of Technology,Tiruchirapalli
Tamilnadu

Research Guide
Dr. N. Siva Shanmugam
National Institute of Technology,Tiruchirapalli
Tamilnadu

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INTRODUCTION

- Ti-6Al-4V is the most commonly used alloy. It has a chemical composition of 6% aluminum, 4% vanadium, 0.25% (maximum) iron, 0.2% (maximum) oxygen, and the remainder titanium.
- It is significantly stronger than commercially pure titanium while having the same stiffness and thermal properties.

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INTRODUCTION

THIS GRADE HAS AN EXCELLENT COMBINATION OF STRENGTH, CORROSION RESISTANCE, BIOCOMPATIBILITY AND WELDABILITY.

Property	Ti-6Al-4V	Stainless Steel	Aluminum
Density	4420 kg/m^3	8000 kg/m^3	2700 kg/m^3
Young's modulus	110 GPa	193 GPa	69 GPa
Tensile strength	1000 MPa	570 MPa	310 MPa

PLASMA ARC WELDING

- Plasma welding has greater energy concentration and allow higher welding speeds and less distortion.
- Three operating modes - By varying bore diameter and plasma gas flow rate
  - Micro plasma : **0.1 to 15A**
  - Medium current : **15 to 100A**
  - Keyhole plasma : **over 100A**

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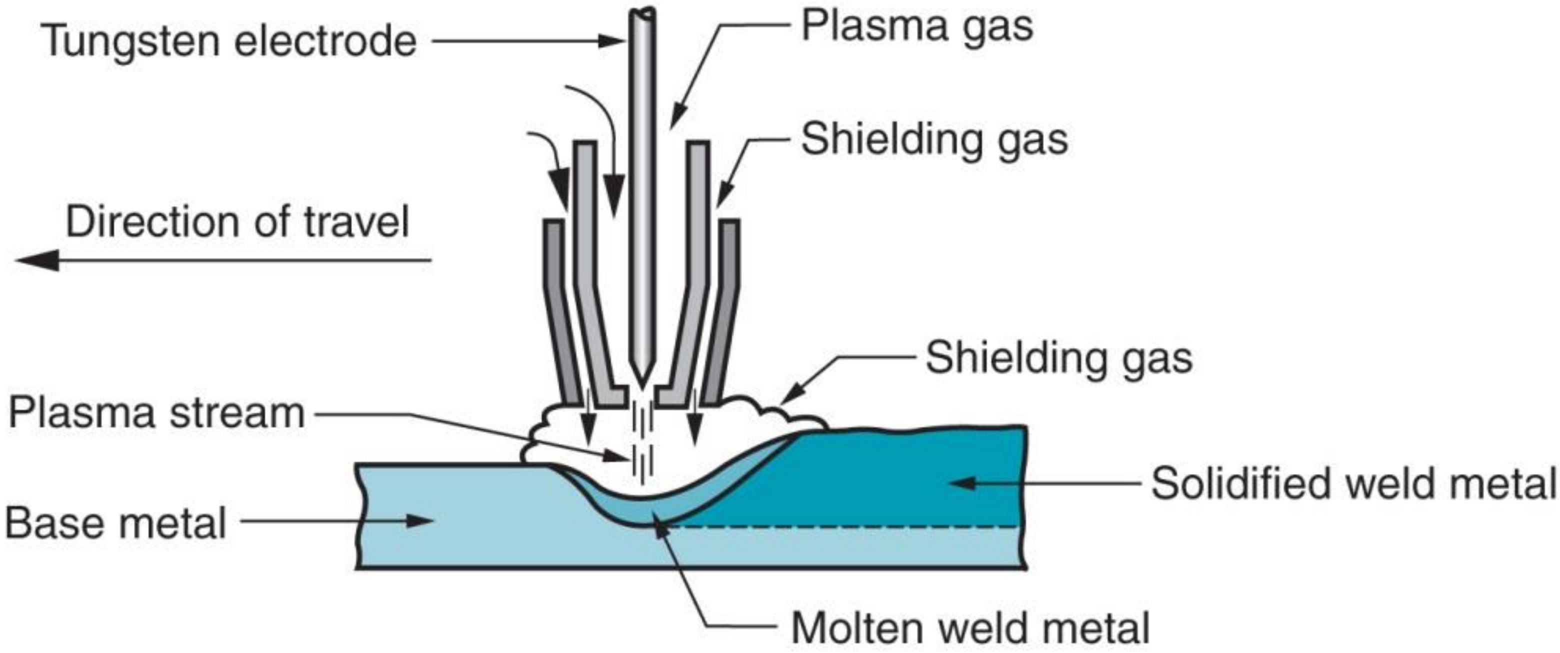
PLASMA ARC WELDING



LITERATURE SURVEY

Sl. No	PAPER TITLE		AUTHORS	DISCUSSION
1	A New Heat Source Model for Keyhole Plasma Arc Welding in FEM Analysis of the Temperature Profile	2006	C.S.Wu, H.G.Wang and Y.M.Zhang	Developed a Modified Three dimension conical heat source model and Quasi steady state PAW heat source to reflect the thermo mechanical process of PAW. MTDC heat source model was implemented for the material having higher thickness
2	Finite element-based analysis of experimentally identified parametric envelopes for stable keyhole plasma arc welding of a titanium alloy, The Journal of Strain Analysis for Engineering Design	2012	Aditya A Deshpande,et.all	A conical heat source model was used to simulate the relationship between welding parameters and welding efficiency and proposed that the relationship is useful for selecting combination of weld parameters and keyhole welding
3	Parametric Envelopes for Keyhole Plasma Arc Welding of a Titanium Alloy	2012	A. Short et.all	Developed parametric envelope for Keyhole PAW of Ti-6Al-4V of sheet thickness of 2.1 mm

PROBLEM IDENTIFICATION

- Based on the literature survey, it is inferred that only limited amount of research work has been carried out by the researchers in the areas of numerical simulation and experimental studies related to plasma arc welding of thin titanium alloy sheets. Hence, an attempt is made through this research work to develop a new heat source model and simulate the plasma arc welding of titanium alloy sheets. The simulation results are compared with the experimental outcomes for validation.

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OBJECTIVES

- To develop a new heat source model for Plasma arc welding thin sheets.
- To perform numerical simulation using COMSOL to predict the weld bead geometry.

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Experimental Set up

Plasma Power Source

Plasma Torch with Trailing Shield

Before using Trailing Shield

After using Trailing Shield

Process Parameters

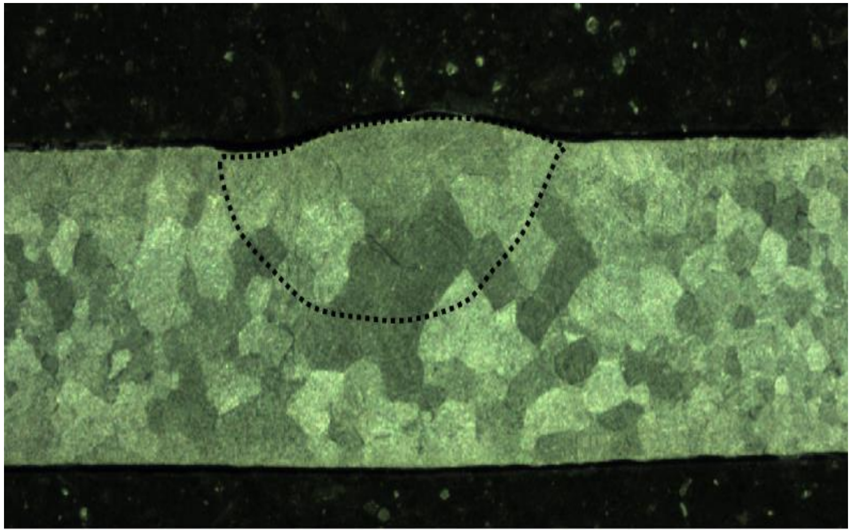
Parameter	Welding Current(A)	Welding Speed(mm/min)	Arc Length(mm)	Gas flow rate , l/min	Shielding Gas Flow rate , l/min
	60	300	8 mm	12	24

Material Dimension

200 X 200 X 2 mm

Weld Bead

Macrograph



Current:60 A , Speed : 300 mm/min

Finite Element Simulation

Mathematical Description of the Model

$$\rho C_p \frac{\delta T}{\delta t} + \rho C_p(-v)\frac{\delta T}{\delta x} = \nabla.(k\nabla T) + Q$$

where

(x,y,z) = coordinate system attached to the heat source

q_v = power generation per unit volume (W m^{-3})

K = thermal conductivity (W m^{-1} K^{-1})

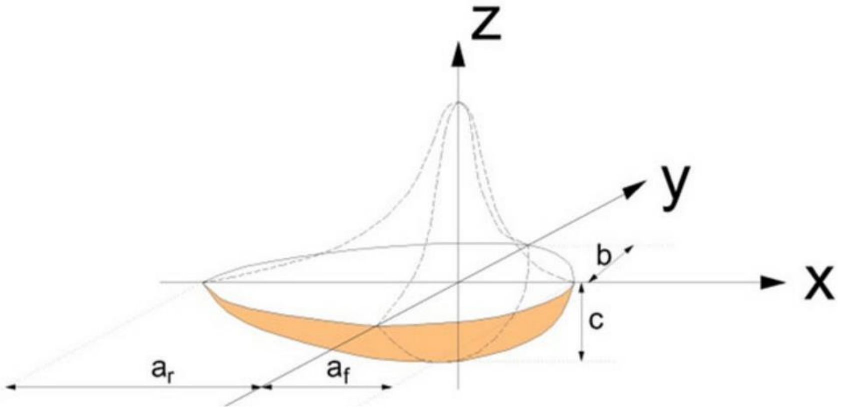
C_p = specific heat capacity (J kg^{-1} K^{-1})

P = density (kg m^{-3})

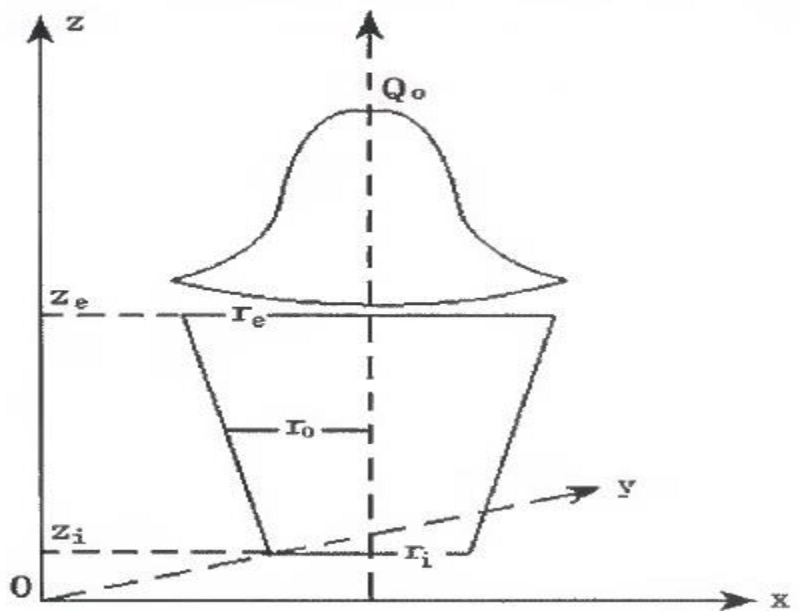
t = time (s)

Heat sources

Gaussian Volumetric Heat Source



Double Ellipsoidal



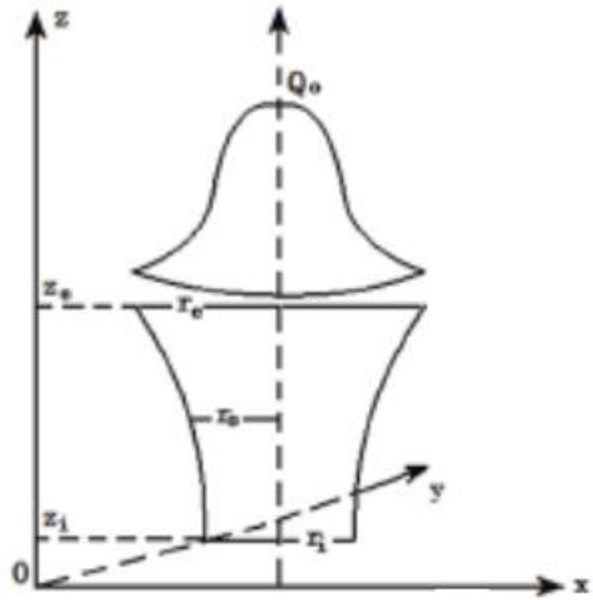
3D Conical Heat Source

Heat sources

$$Q(r,z) = Q_0 \exp\left(-\frac{3r^2}{r_0^2}\right)$$

$$r_0(z) = a \ln z + b$$

$$a = \frac{r_e - r_i}{\ln z_e - \ln z_i} \qquad b = \frac{r_i \ln z_e - r_e \ln z_i}{\ln z_e - r \ln z_i}$$



$$A_v = a^2\left[(H + z_i)\ln^2(H + z_i) - z_i \ln^2 z_i\right] - 2a(a-b)$$
$$\left[H + z_i)\ln(H + z_i) - z_i \ln z_i - H\right] + b^2 H$$

$$Q_0 = \frac{3\eta VIe^3}{A_v \pi (e^3 - 1)}$$

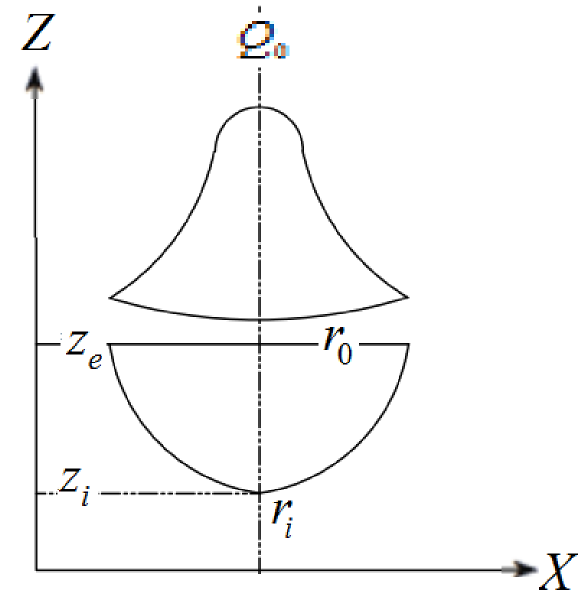
Newly Developed Heat Source

$$Q(r,z) = Q_0 \exp\left(-\frac{3r^2}{r_0^2}\right)$$

$$r_0(z) = a z^2$$

$$Q_0 = \frac{3\eta V I e^3}{A_v \pi (e^3 - 1)}$$

$$A_v = (a^2/5)\left[(H + z_i)^5 - z_i^5\right]$$



Boundary Conditions

The initial condition is $T(x,0,z,t) = T_0(x,y,z)$

The essential boundary condition is $T(x,y,z,0) = T_0(x,y,z)$

The natural boundary conditions can be defined by

$$k_n \frac{\partial T}{\partial n} - q + h(T - T_0) + \sigma\varepsilon\left(T^4 - T_0^4\right) = 0$$

where

k_n **is thermal conductivity normal to the surface (W/m K)**

q **is prescribed heat flux (W/m^2)**

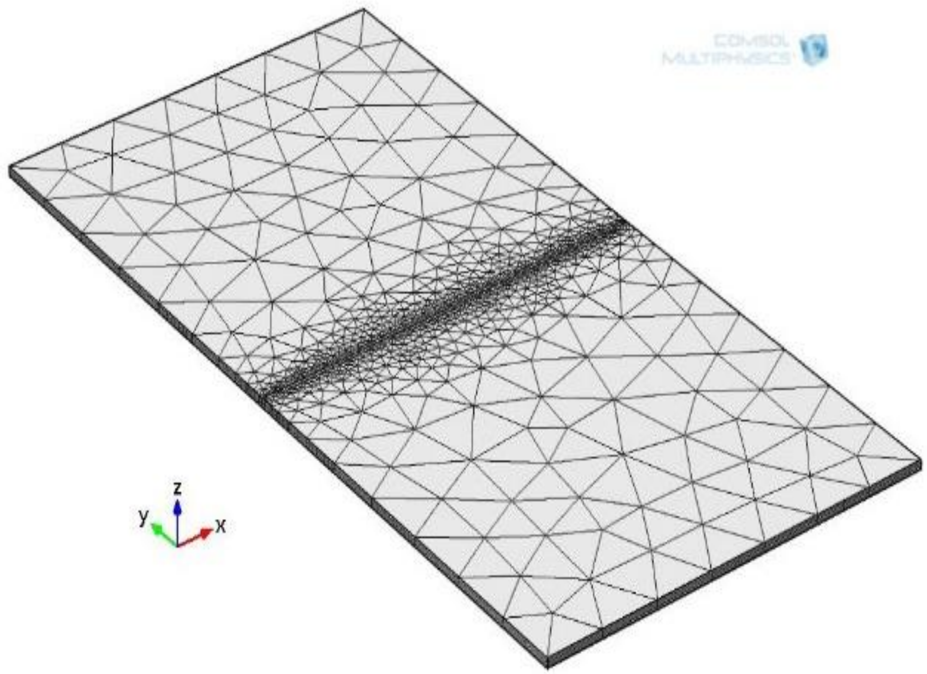
h **is heat transfer coefficient for convection (W/m^2 K)**

σ **is Stefan-Boltzmann constant for radiation (5.67 x 10 $^{-8}$ W/m^2 K^4)**

ε **is emissivity**

T_0 **is ambient temperature (K)**

3D Finite Element Model(35893 nodes and 8047 elements)



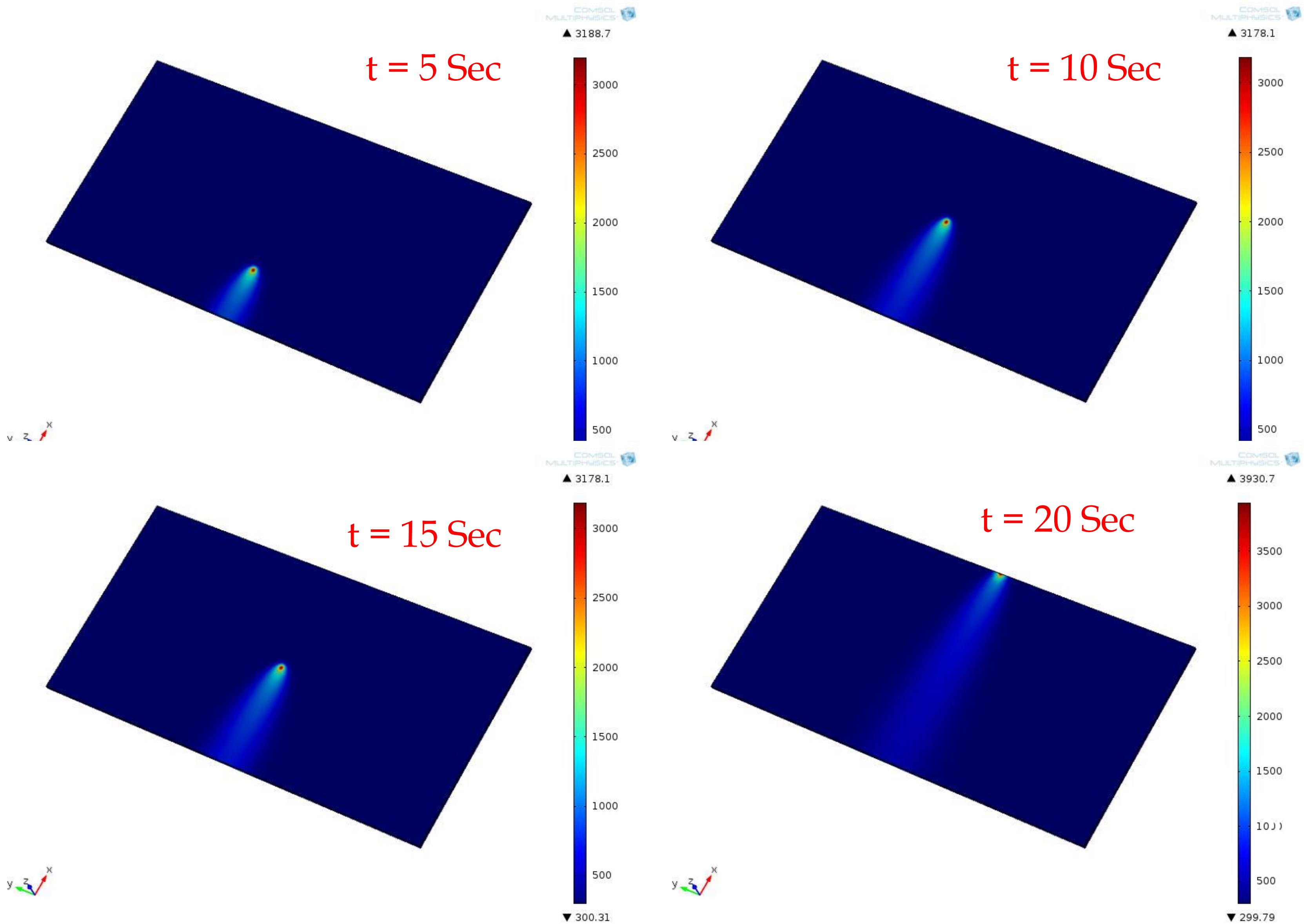
The assumptions made in this investigation are:

- The plasma arc is moving with a constant speed over the work piece
- Thermal material properties namely conductivity, specific heat, density are temperature dependent.

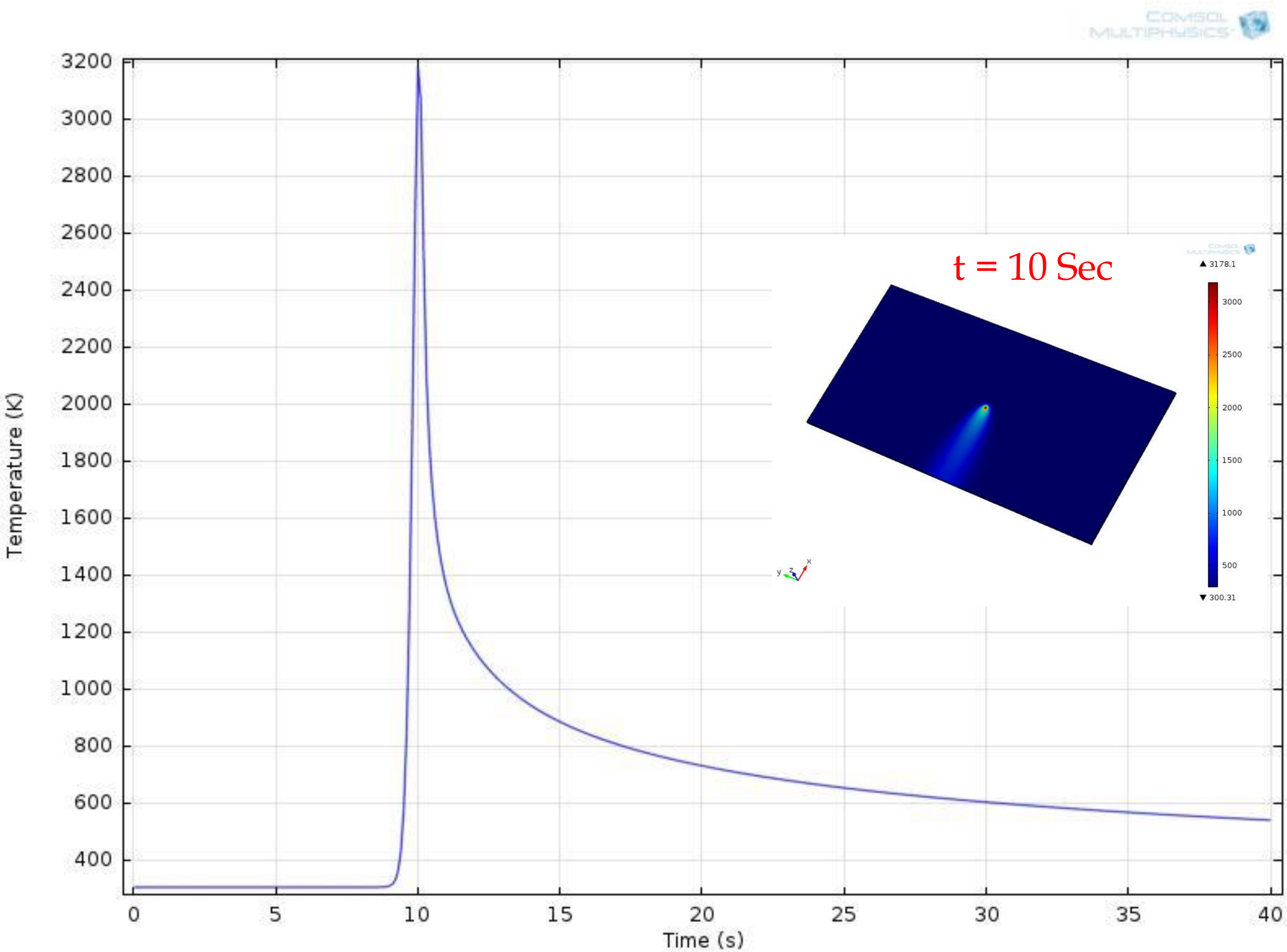
Heat source Parameters

Parameter	Value	Unit
r_e	1.38	mm
r_i	0.001	mm
$H=z_e-z_i$	1.04	mm
Speed	300	mm/min
Efficiency	0.5	---

Temperature distribution at different timing on top surface of the plate



Temperature vs. Time



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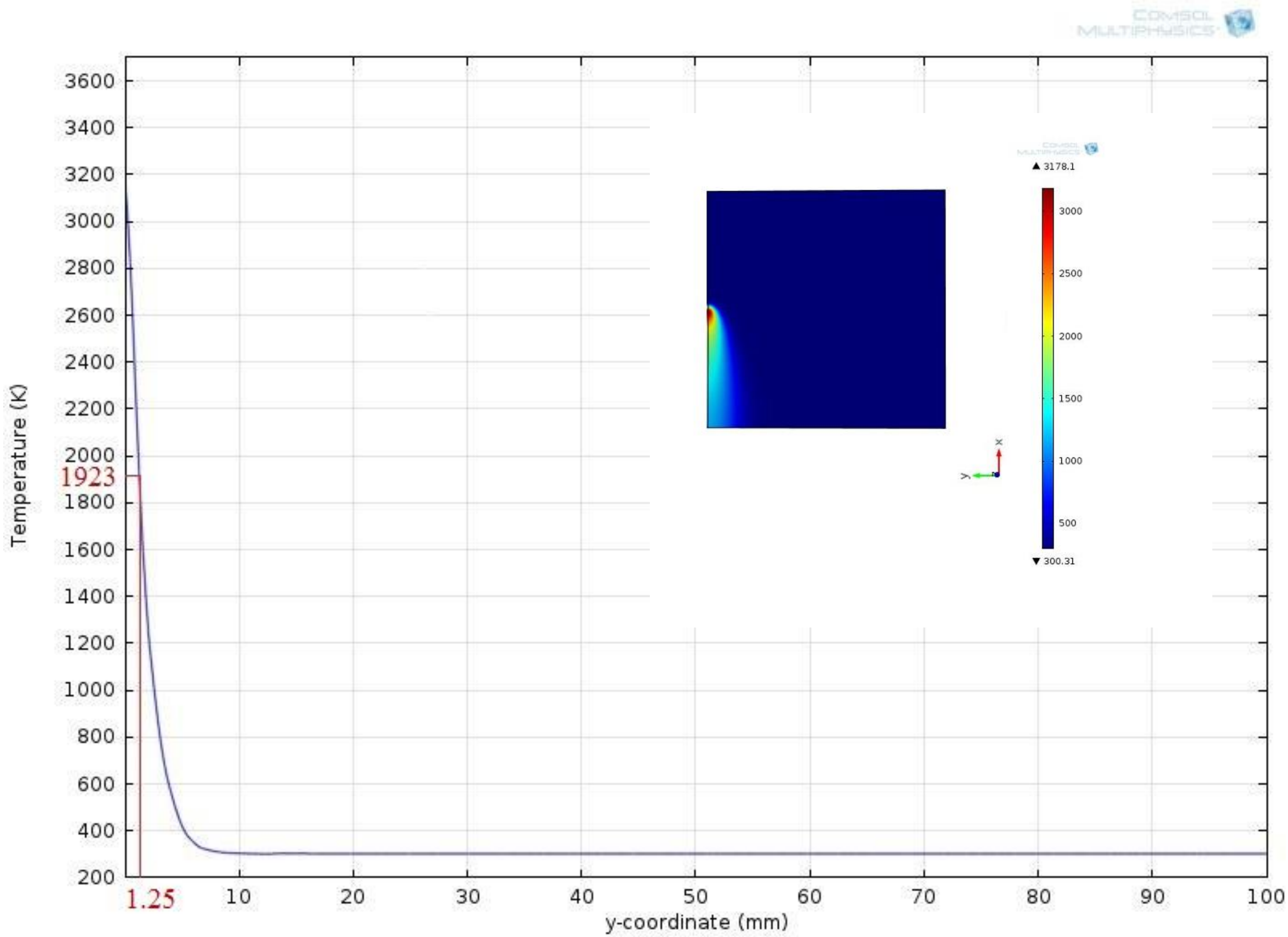
Temperature distribution along transverse direction



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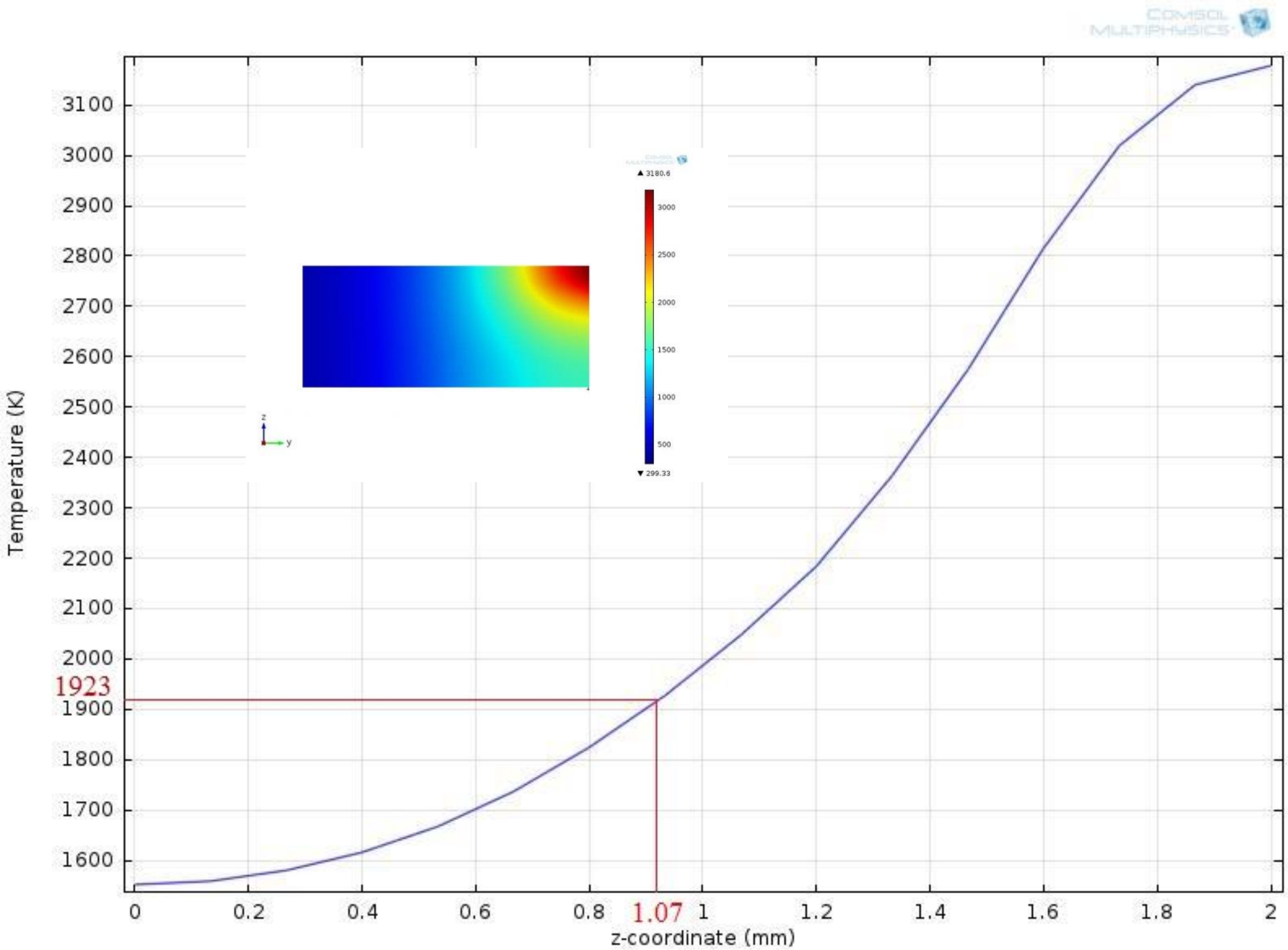
Temperature distribution along thickness of the plate



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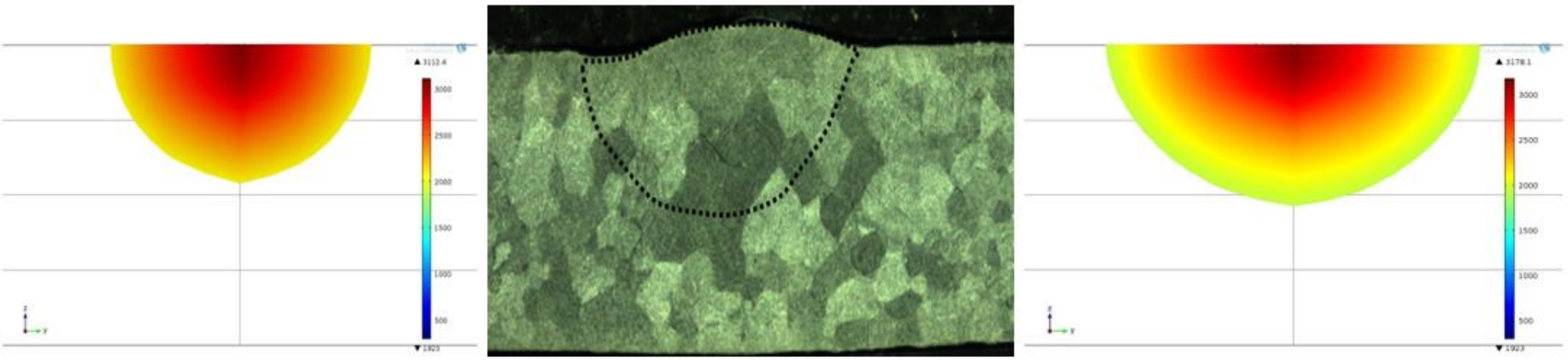
Macrograph



(a) (b) (c)

Macrograph (a) MTDC (b) Experimental (c) Newly developed heat source

Comparison weld bead parameters

Parameter	Bead Width	Depth of Penetration
MTDC	2.0 mm	0.9 mm
Experimental	2.75 mm	1.07 mm
Newly Developed Heat Source	2.5 mm	1.05 mm

INFERENCES

- Based on the investigation, it is inferred that the predicted weld bead geometry using newly developed three dimensional heat source model is observed to be in good agreement with the experiment result.The effect of input process parameters on weld bead geometry of Ti-6Al-4V are investigated.

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FUTURE WORK

- Weld pool phenomenon is very complicated since lot of force are force incurred.
    - Electromagnetic force
    - Aerodynamic drag force
    - Gravitational force
    - Vapour Jet force
    - Surface tension force

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