A COMPUTATIONAL FLUID DYNAMIC STUDY ON TRANSIENT THERMAL CHARACTERISTICS OF TWO-PHASE GAS METAL ARC WELDING PROCESS

N.Yagnesh Sharma[1], Chandrakanth Kini [1], Deepak D[1] and Pratik Shamrao Joshi[2]

[1]Professor, Dept. of Mechanical & Manufacturing Engineering,
Manipal Institute of Technology,
Manipal University, Manipal, India

[2]Assistant Professor, Dept. of Mechanical Engineering,
Adarsh Institute of Technology and Research Center, Vita. - 415311
Shivaji University, Kholapur, Maharastra, India

ABSTRACT

Gas Metal Arc Welding (GMAW) is a welding process where an electrode wire is continuously fed from an automatic wire feeder through a conduit and welding gun to the base metal, where a weld pool is created. The formation of droplet and transfer of droplet are governed by the conservation equations. This study on GMAW aims to simulate transient behavior of welding arc and shielding gas flow. Computational Fluid Dynamics (CFD) is used as a tool to understand multifaceted physics involved in GMAW process. A two dimensional axisymmetric model is prepared to reduce computational time. The heat transfer and fluid flow in the arc column were studied based on the transient distributions of velocity, turbulence, voltage, current density, and temperature. An interactive coupling between welding arc, plasma, current and temperature were considered. The assumed steady state and laminar gas flow in traditional models studied so for does not reflect the real distributions in the welding process. Hence influence of the welding arc on the shielding gas flow and vice versa was taken up for study. From the study it is found that as the arc is struck, the shielding gas is accelerated towards axis. When the plasma reaches towards workpiece, axial momentum of gases is changed to radial momentum and flows away from the workpiece. The shielding gas also carries current from electrode to workpiece which helps in reducing spatter of the arc and hence concentrated arc is obtained

Key Words: *Gas Metal Arc Welding, Numerical Modelling, transient analysis, shielding gas*

1.INTRODUCTION:

GMAW is a common welding process used in conditions where air current is not too damaging to the external shielding gas which is used to protect the weld pool. External shielding gases have different compositions, allowing the electrode wire to change mode conversions if proper voltage and current parameters are used [1]. Shielding gas composition also affects bead appearance and fusion. The essential function of a shielding gas is to protect the molten weld metal from atmospheric contamination and the resulting imperfections [1]. In addition to its shielding function, it has specific physical properties that can have a major effect on welding speed, penetration, mechanical properties, weld appearance, shape and arc stability. Many researches have carried out to studies on Gas Meal Arc Welding(GMAW). Many of these studies, do not consider actual geometry parameters of the nozzle which affect the inert gas flow & the weld quality. Also the gas flow is assumed to be laminar in these studies, whereas in actual process gas flow it is highly turbulent.

Some research has also been done to study the transient effect of welding parameters in the arc plasma. Anthony B. Murphy [2] calculated the transport properties of the arc plasma.. Theoretical calculations of the plasma transport properties are very approximate due to complex nature of the plasma behavior and inexact knowledge of the collision cross section values. However these calculations are very useful in determining plasma properties. T.W. Eagar et.al, [3] studied the droplet size produced during GMAW both theoretically and experimentally. Study is carried out basically on static force imbalance theory and their application in GMAW process. P.G. Jonsson et. al. [4] studied the arc parameters and the metal transfer in GMAW process using mild steel and helium and argon gases as shielding gases. A two dimensional steady state model has been prepared to study the arc parameters such as temperature, electric potential, and velocity. J. Hu, H.L. Tsai [5] prepared a unified comprehensive model to simulate transient phenomenon occurring during the GMAW process. Based on the unified model, a thorough investigation of the plasma arc characteristics during the gas metal arc welding process was conducted. M. Schnink, M.Dreher [6] studied experimental methods for visualization and quantification of gas flows in GMAW process. Advanced Particle Image Velocimetry (PIV) and Schilerin technique were used for characterization of flow field in the direct vicinity of the arc. H.G. Fan et.al. [7] prepared a theoretical model describing globular transfer in GMAW process. The heat and mass transfer in the electrode, arc plasma and molten pool are considered in one unified model. G. Wang et.al [8], proposed a method to pulsate current in GMAW to achieve a specific type of desirable and repeatable metal transfer mode. This method uses a peak current lower than the transition current to prevent accidental detachment and takes advantage of downward momentum of the droplet to enhance the detachment. U. Fussel et.al[9], studied the shielding gas flow inside the welding torch and free jet between the gas nozzle and the workpiece. The arc model includes a MHD model and a LTE assumption near the electrode region. Takehiko TOH, Jun TANAKA et.al [10] studied the behavior of DC arc plasma under a magnetic field imposed perpendicular to the plasma current. The behavior is studied both theoretically and experimentally by changing various parameters such as plasma electric current, nozzle diameter, argon flow rate and magnetic flux density. DC plasma was mathematically modeled by use of three dimensional magneto hydrodynamics (MHD) theory and numerical simulation performed using finite volume approach. By experimental and theoretical analysis controlling parameters of DC plasma are stated.

2.NUMERICAL MODELLING AND METHODOLOGY:

The problem being taken up for the computational analysis pertains to GMAW process. This welding region is a two phase domain consisting of mixture of molten metal and shielding gas. The numerical computation is used to explore the fluid flow and heat transfer characteristics of molten metal in the presence of shielding gas. The phenomenon of GMAW is assumed to be steady state and laminar gas flow in traditional models where as in real process gas flow is highly turbulent and transient. The need for determining the effect of nozzle geometry on shielding gas flow and consequently on welding bead characteristics is felt much in actual GMAW process and therefore the problem will be solved covering both. When an arc is struck between anode and cathode, current flows through electric discharge created between them. The arc current spreads laterally from anode spot and jet is formed which gives rise to flow of electrons towards the cathode. The gas impinges on to the workpiece and is spread in a direction parallel to the workpiece. The current distribution around anode generates huge amount of heat which causes melting of the electrode. Droplets form at the tip of the electrode and detaches from the electrode due to arc forces. Droplets formed are transferred to workpiece. The melted droplets solidify at the workpiece and form a part of welded joint.

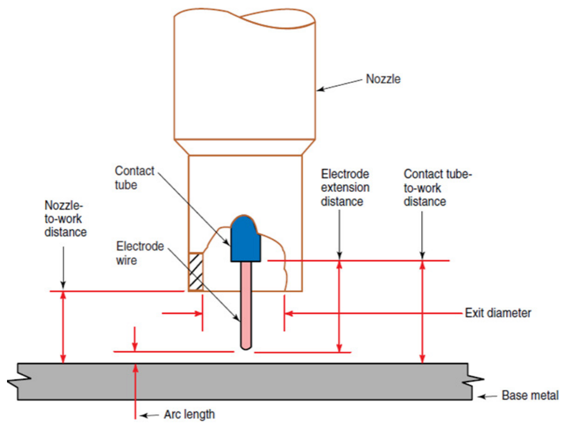


Fig.1 Physical model and parameters to be considered for geometry [11]

2.1.Numerical Model :

An axisymmetric meshed model is prepared as shown in Figure 2. An axisymmetric model is used so as to reduce computational time. Angle for the nozzle is 60^0. There are two zones present namely solid and fluid. Electrode is assigned as solid while all other remaining zones are assigned as fluid region. Velocity inlet boundary condition is employed where gases enter into domain and outlet vent is assigned from where gases come out. All other boundaries are assigned as wall condition. Figure 3 shows meshing of the domain. For meshing of solid domain quad mesh with map scheme is utilised, whereas for meshing of fluid domain quad mesh with pave scheme is utilised. Total numbers of elements are 89553 and nodes are 90104. After meshing the mesh file is successfully exported for solver.

The analysis is carried out through multiphase, energy, viscous and MHD models. Multiphase model with volume of fluid (VOF) technique is used. The VOF model is surface tracking technique applied to a fixed mesh. It is designed for two or more immiscible fluids are present in the computational domain. As there are two fluids present one is molten metal and another is mixture of gases argon and oxygen, VOF technique is thereby used. Energy model is activated to account for turbulence model using standard k-ε model. The standard k- ε model is a model based on model transport equations for turbulent kinetic energy (k) and its dissipation rate (ε). Finally MHD model, which is available in Fluent software as an add-on model, is activated.

2.2.Governing Equations used in the Numerical Formulation (in polar coordinate system):

The Governing equations are based on the following assumptions [4]

1. The arc is axially symmetric.
2. The arc is in local thermodynamic equilibrium i.e, the electron and heavy particle temperatures are nearly same.
3. The plasma is optically thin so that radiation may be taken into account.
4. The consumable electrode is cylindrical in shape and tip of the electrode and workpiece are flat.
5. The consumable electrode is in quasi-steady state.

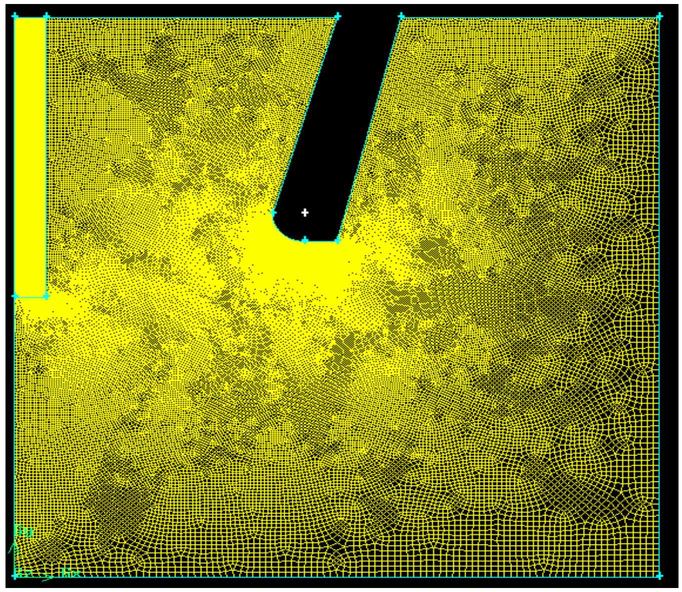


Fig.2 Axi-symmetric Meshed of domain used for Computation

2.3.Conservation of Mass:

The transport equation for conservation of mass is given as

$$\frac{\partial \rho}{\partial t}+\frac{1}{r}\frac{\partial(\rho ru)}{\partial r}+\frac{\partial \rho w}{\partial z}=0 \qquad (1)$$

Where ρ = mass density in kg/m^3, r =radial distance in m, z= axial distance in m, u = radial velocity in m/s, w= axial velocity in m/s

2.4.Conservation of Radial Momentum:

$$\frac{\partial \rho u}{\partial t}+\frac{1}{r}\frac{\partial(\rho ruu)}{\partial r}+\frac{\partial \rho uw}{\partial z}=-\frac{\partial P}{\partial r}+\left[\frac{2}{r}\frac{\partial}{\partial r}\left(\mu r\frac{\partial u}{\partial r}\right)-\mu\frac{2u}{r^2}+\frac{\partial}{\partial z}\left(\mu\left\{\frac{\partial u}{\partial z}+\frac{\partial w}{\partial r}\right\}\right)\right]-J_zB_\theta \qquad (2)$$

2.5.Conservation of Axial Momentum:

$$\frac{\partial \rho w}{\partial t}+\frac{1}{r}\frac{\partial(\rho ruw)}{\partial r}+\frac{\partial \rho ww}{\partial z}=-\frac{\partial P}{\partial z}+\left[\frac{1}{r}\frac{\partial}{\partial r}\left(\mu r\frac{\partial u}{\partial r}+\frac{\partial w}{\partial r}\right)-2\frac{\partial}{\partial z}\left(\mu\left\{\frac{\partial w}{\partial z}\right\}\right)\right]-J_rB_\theta \qquad (3)$$

Where Jr=radial current density in A/m^2, Jz= Axial current density in A/m2, P= Pressure in N/m^2, μ= Viscosity in N-s/m^2, B_θ=Azimuthal magnetic field in Tesla in equations (2) and (3)

2.6.Conservation of Energy:

$$\frac{\partial \rho h}{\partial t}+\frac{1}{r}\frac{\partial(\rho ruh)}{\partial r}+\frac{\partial \rho wh}{\partial z}=\frac{1}{r}\frac{\partial}{\partial r}\left(\frac{kr}{c_p}\right)\frac{\partial h}{\partial r}+\frac{\partial}{\partial z}\left(\frac{k}{c_p}\right)\frac{\partial h}{\partial z}+\frac{J_z^2+J_r^2}{\sigma_e}-S_R+\frac{5K_b}{2e}\left(\frac{J_r}{c_p}\frac{\partial h}{\partial r}+\frac{J_z}{c_p}\frac{\partial h}{\partial z}\right) \qquad (4)$$

Where h= Enthalpy in joule, k=Thermal conductivity in w/m-k, C_p=Specific heat at constant pressure,

σ_e =Electrical conductivity in1/Ω-m , S_R=Radiation heat loss ,K_b=Boltzmann constant (8.617 332× 10−5 eV/k), Elementary charge (1.602176× 10^{-19} C)

2.7.Conservation of Electric Charge:

$$\frac{1}{r}\frac{\partial}{\partial r}\left[\sigma_e r\frac{\partial\phi}{\partial r}\right]+\frac{\partial}{\partial z}\left[\sigma_e\frac{\partial\phi}{\partial z}\right]=0 \tag{5}$$

Where Ø=Electric potential in V. The current density can be obtained from Ohm's law which is given by,

$$J_r=\sigma_e\frac{\partial\phi}{\partial r} \quad ; \quad J_z=\sigma_e\frac{\partial\phi}{\partial z} \tag{6}$$

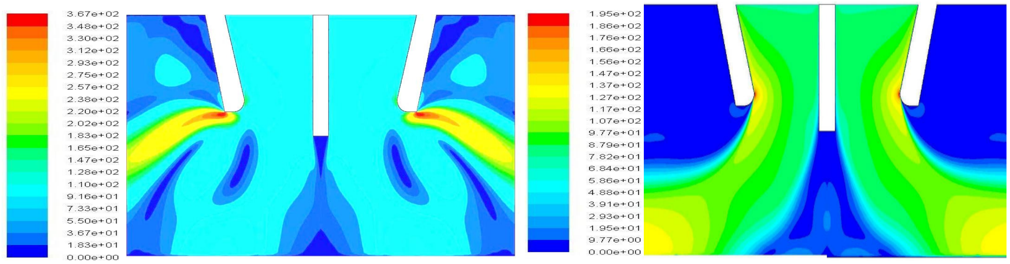
3.RESULTS AND DISCUSSION:

The results are plotted in the forms of contours and graphs of velocity, temperature, turbulence, joule heat, electric potential. In this present work the current value is set at 275A and electrode diameter to 1.6mm. The simulation is carried out as a transient simulation and results of simulation becomes steady at 800 milliseconds.

3.1.Transient Velocity and Turbulence Characteristics:

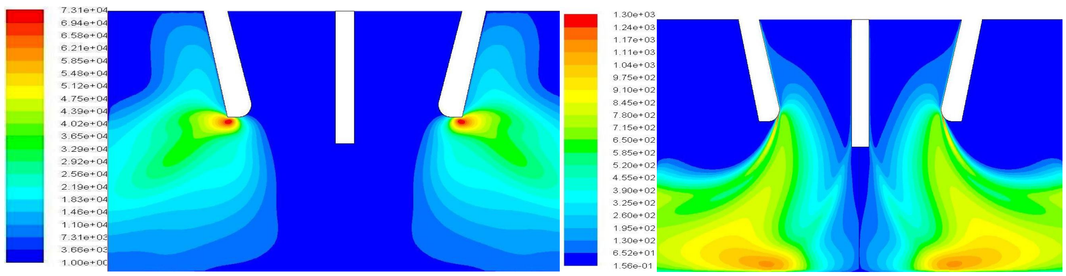
Figure 3 shows the contour plot of free jet velocity of shielding gas coming out of nozzle. The high velocities and turbulence affect the flow field between gas nozzle and workpiece. At t=100 ms gas flow found to be dispersed in the domain since gases comes out from converging nozzle, velocity of gas suddenly increases and flows in the area between nozzle and workpiece. As the welding arc is struck, the gases start ionizing and plasma is created. Due to the arc effects, gas is accelerated towards the axis of the arc. When the plasma flow reaches the workpiece, the axial downward momentum is changed to radial outward momentum and plasma flows outward in radial direction. As the time progresses the flow becomes steady and a maximum velocity of flow becomes 195 m/s. The maximum flow velocity is in well agreement with experimental results [6], [7].

Figure 4. shows contours of turbulent kinetic energy. The numerical model predicts the formulation of high velocities and eddies in the flow area. At t=100 ms eddies are found at the exit of the nozzle. Initially turbulent kinetic energy value was $7.31e^4$ m^2/s^2. As initially gases velocity increases abruptly, the high amount of turbulence is considerable. As time progresses, gas flow becomes steady and hence turbulence inside flow region reduces. At steady state value of turbulent kinetic energy is $1.39e^3$ m^2/s^2. Eddies are found near the workpiece away from the weld region. These eddies are essential to prevent other atmospheric gases into weld region and prevent welding defects. As temperature in weld region is about 20,000K, there is possibility of oxidation of weld bead. Hence it is necessary to prevent atmospheric gases to enter into weld region. There is small amount of turbulence near weld region which is undesirable.



t=100 ms t=800 ms

Fig. 3. Contours of velocity in m/s

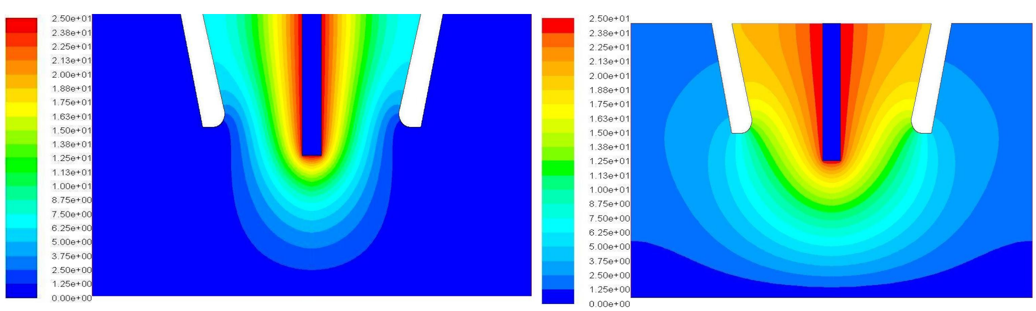


t=800ms t=100ms

Fig 4 contours of turbulent kinetic energy in m^2/s^2

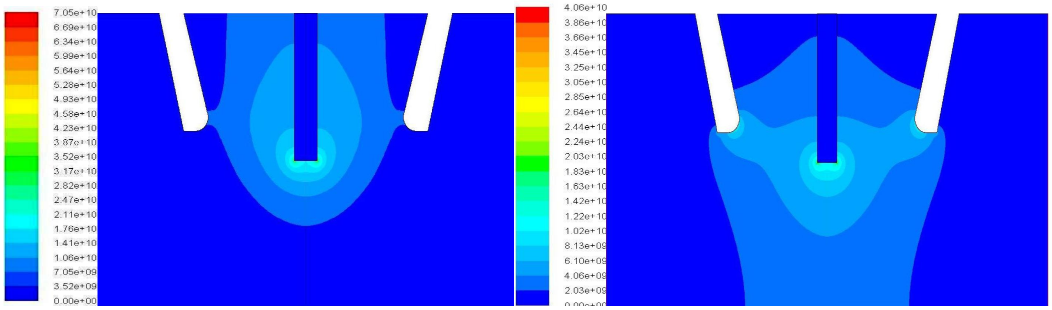
3.2.Electric Potential and Current Density:

Figure 5. shows contours of electric potential in the region between electrode and workpiece. There are two distinct regions are observed where dense electric potential contours are observed. One is around electrode with upside contour and another is at cathode with downside contour. The gradient of electrical potential is current density. Figure 6 shows contours of electric current density. The electric potential contours are denser where the current density is higher.



t= 100 ms t=800ms

Fig. 5 Contours of electric potential

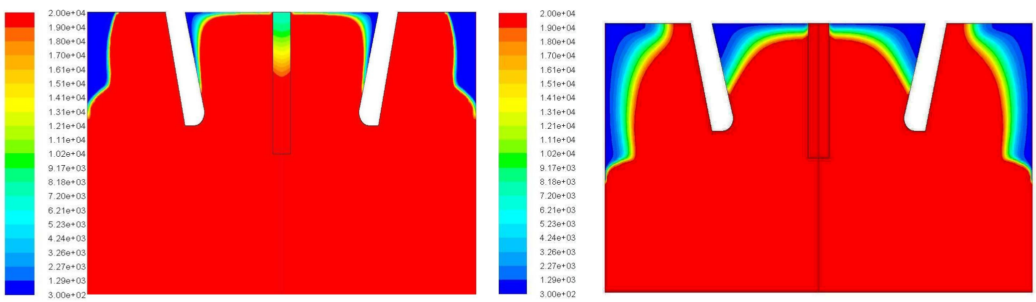


t=100ms t=800ms

Fig. 6. Contours of electric current density in A/m^2

3.3.Transient Temperature field:

Figure 7 shows contours of temperature. As there is high amount of heat generated, the amount of temperature generated is also high. The instantaneous temperature near the electrode is near about 20000K. At start the temperature increases rapidly, as enormous heat is generated. The temperature in the system starts reducing as gases comes into the action. The inert gases cause rapid cooling of the system. Gases while flowing over the work piece carries heat away from the weld region causing reduction in temperature of weld region.



t= 100 ms t= 800ms

Fig.7 contours of temperature in K

4.CONCLUSION:

A numerical model has been developed to simulate the complex transport phenomenon in Gas Metal Arc Welding. The heat transfer and fluid flow in the arc column were studied based on the transient distributions of velocity, turbulence, voltage, current density, joule heat and temperature. An interactive coupling between welding arc, plasma, current and temperature were considered. The assumed steady state and laminar gas flow in traditional models were not to be real distributions in the welding process. The influence of the welding arc on the shielding gas flow and vice versa was analyzed. The arc stabilizes the shielding gas flow. The shielding gas also carries current from electrode to workpiece which helps in reducing spatter of arc and concentrated arc is obtained. The numerical model will be further developed for the use of GMA welding.

REFERENCES

[1] Praxair Shielding Gas Selection Manual; http://catalogs.praxairdirect.com/i/30913/106

[2] Anthony B. Murphy, “Transport coefficients of helium and argon plasmas”, IEEE transaction on plasma science,Vol.25, Oct. 1997

[3] T.W. Eagar and Y.S. Kim, “Analysis of metal transfer in gas metal arc welding”, Welding research supplement, June 1993

[4] P. G. Jonsson and J. Szekely, “Heat and mass transfer in gas metal arc welding using argon and helium”, Metallurgical and Materials transaction B, Volume 26B, April-1995, 383-395

[5] J. Hu, H.L. Tsai, “Heat and mass transfer in gas metal arc welding”, International journal of heat and mass transfer, Vol.50,Oct. 2006,833-846

[6] M. Schnink, M. Dreher, “Visualization and optimization of shielding gas flows in arc welding”, Welding in the world, Vol.56, 2012

[7] H.G. Fan and R. Kovacevic, “A unified model of transport phenomenon in gas metal arc welding including electrode, arc plasma”, Journal of physics D: Applied Physics, Vol. 37, 2531-2544, 2004

[8] G.Wang, P.G. Huang, Y.M. Zang, “Numerical analysis of metal transfer in GMAW under modified pulsed current condition”, Metallurgical and material transaction B, July-2003. [9]U. Fussel, M.Dregher, M. schinck, “Numerical optimization of GMAW torches using ANSYS CFX”, 63rd Annual assembly and International conference of international institute of welding, Istanbul, Turkey, 11-17 July 2010.

[10] Takehiko Toh, Jun Tanata, Yasho Maruki, “Magneto hydrodynamic simulation of D.C. arc plasma” ISIJ International, Vol.45, , 947-953, 2005

[11] Larry Jeffus, “Welding principles and applications”, Delmar publications, 4th edition, ISBN 0-8273-8240-5

Authors

Dr. N.Yagnesh Sharma, Professor in the department of Mechanical & Manufacturing Engineering, obtained his B.E. degree in Mechanical Engineering from University of Mysore in 1978, and M.Tech. (Thermal Turbomachinery) from Indian Institute of Technology, Madras in 1981. He was awarded PhD degree for his doctoral work in the area of Gas Turbine Combustion from Indian Institute of Technology (Kharagpur) in 2002. His research interests are in the area of Droplet combustion in gas turbine, Computational fluid dynamic studies on cooling of gas turbine blades, Numerical modeling and analysis of solar air and water heaters, Turbomachinery flows and Water Jet Cutting Process. He was recognized for his distinguished service of 25 years to MIT, by Manipal University in 2007. He is a Life Member of Institution of Engineers and ISTE.

Pratik Shamrao Joshi is Assistant Professor, Dept. of Mechanical Engineering, Adarsh Institute of Technology and Research Center, Vita. – 415311, Shivaji University, Kholapur, Maharastra, India

Chandrakant R Kini is Research Scholar in the Department of Mechanical and Manufacturing Engineering, Manipal Institute of Technology, Manipal University, India. He has B.E in Mechanical Engineering and M. Tech in Thermal Engineering from NITK, Surathkal. Presently he is doing PhD. His area of research includes CFD analysis of Gas Turbine Blade cooling.

Deepak D is Assistant Professor in the department of Mechanical and Manufacturing Engineering, Manipal Institute of Technology, Manipal University, India. He has obtained B.E (2003) and M. Tech (2005) in Manufacturing Engg. from National Institute of Engineering, Mysore. Presently he is pursuing Ph.D in Manipal University. His area of research includes CFD analysis and Advanced manufacturing process. He is a member of International Association of Engineers (IAE).