Computational Investigation of Heat Transfer and Mass Flow in GTA Welding of AA6061 Plates

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Abstract

Computational approach or numerical simulation is a trend in recent manufacturing technology, in the present study a computational approach is made for a pulse type GTAW to analyze the heat transfer and mass flow behavior using FEA software ANSYS 19.0. Transient thermal simulations are carried at three different heat inputs in the form of voltage and currents with the welding speed of 70mm/min. The heat source profiles are obtained with the different heat inputs from experimental investigations. The same heat source profiles are modeled using the Solid EDGE software and called in the ICEM CFD to generate grids with unstructured tetrahedral mesh and grids are also made for the workpiece by modelling for a dimension of 150mm X 100mm having 6mm thickness same as the experimental workpiece. The generated Finite element model is called in ANSYS Workbench for transient thermal simulations to obtain the temperature distributions and the heat source models are also called in ANSYS Fluent for velocity field. The heat source models selected and the temperature field obtained from the computational numerical simulations are in good agreement with the experimental results indicating validation of the simulation process made.

Keywords: Gas tungsten arc welding; hemispherical heat source model; heat transfer; fluid flow; modeling; temperature field.

1.0 Introduction

Welding is a most popular metal joining technique for fabricating metals, alloys thermoplastics, etc. by applying heat or pressure. The welding process involves melting of metals, addition of filler metal forming a weld bead or weld pool and quick solidification forming a joint. Improper Welding leads to the formation of cracks, residual stresses, distortion, gas contamination, improper fusion, lack of penetration etc. are identified in and around a weld joint. These obstructions may occur due to the intense heat input on welds forming an improper thermal cycle. Therefore it is required to carry the investigations on thermal behavior in all types of welding. The heat transfer and mass flow in welding help us to study the best fit welds to avoid defects. In the last few decades investigations on heat transfer and fluid flow behavior are carried experimentally as well as numerically. Experimentally validated numerical simulation in today's research plays an important role in manufacturing techniques. Arc welding is a most popular, widely used, diversified type of welding where the electric arc is utilized as the heat source. The joint is created by means of the arc developed between electrode or a filler metal and the workpiece. The weld joint is formed by the high intense heat that melts the workpiece to be joined and also the filler metal at the joint. Arc welding requires electric current to conduct; this is accompanied by the filler metal to the job. The filler metal may be consumable which helps in formation of slag to protect the molten weld pool from oxidations or non consumable which produces welds by melting the jobs only. Gas Tungsten Arc Welding is a type of Arc Welding which uses the non consumable Tungsten electrode and Argon as the shielding gas. Gas Tungsten Arc Welding is most widely used in automobiles that require high quality precision welding. TIG welding may be continuous and pulsate in producing joint. Therefore thermo mechanical analysis during the GTAW is very important and the welding occupies a geometrical shape with distinct profile producing a Gaussian distributed hemispherical heat source metal hence the welding sequence and optimization of GTAW are significant. The modelling of GTAW is quite complex as the fluid, electric, magnetic and thermal interactions takes place during welding.

Several investigations are carried with respect to FEM analysis by developing numerical models and evaluations are carried mathematically and by using numerical simulation software like ABACUS, COSMOS, SYSWELD, ANSYS etc. to investigate heat and mass transfer in different applications of welding. Friedman [2] made a transient thermal analysis by using Finite Element Method to evaluate different welding parameters like heat input, temperature field for different weld bead geometry on surface and depth of weld for optimizing the welding method. Kurtz and Segerlind [3] developed a FEM model to which is of non linear type to achieve the best welding requirements to obtain a strong joint welded joint. This model helps in achieving the obtaining best metallurgical structure. Goldak et al. [1] studied on transient thermal behavior for the stress in welds by investigating a Finite element model which is Double ellipsoidal modal and is most popularly used in many arc welding applications. The temperature distribution results obtained from this non linear, transient heat flow analysis for arc welds and are validated with the experimentally obtained temperature data of Christensen et al. [4]. Tekriwal and Mazumdar [5] made a Finite Element Analysis by for arc welding using the numerical simulation software ABACUS. In this approach a 3-D transient heat conduction model was investigated. This numerical simulation are made to predict the weld Zone geometries and the Weld zone is compared with the experimentally predicted values of weld Zone geometries carried out by United States Army Construction Research Laboratory the results are validated. Bonifaz [6] developed two dimensional non linear FEM model to investigate the thermal behavior in the Welds. In this study thermal efficiency is adopted to estimate the heat input used for welding by FEM code COSMOS. In this study also the results are compared with the works carried by Christensen et al. [4], Kurtz et al. [3] and Goldak et al. [1]. Silva Prasad et al. [7] studied thermal behavior in welds by adapting a transient grid technique which gives finer mesh around the weld. This technique is adapted for the 3-D transient heat source FEM model and the study helps in increasing the accuracy and computational efficiency of the analysis. Thus the many studies were carried to study the thermal behavior in welds by different approach. But, ANSYS in the today's world is leading software in the computational approach hence many studies are made in the welding simulation using ANSYS Workbench. Kumarsen et al. [8] made a numerical simulation on for the heat transfer behavior to evaluate the residual stresses developed in butt joint of aluminium work pieces. In this study the numerical simulations are done through ANSYS software package and employs element death and birth code for Gas Tungsten Arc welding applications and the simulations also considers the addition of filler metals. Zhu and Chao [9] studied on the thermo mechanical properties of material effects on temperature field and distortion in materials due to stresses. They made numerical simulation for the thermal and mechanical behavior of the metals in welding. It was observed that material properties like yield stress and material conductivity have an effect on residual stresses and temperature field on the weldment. Manurunga et al. [10] carried out an experimental and numerical investigation to determine the effects due to welding on angular distortions which involves thermo-mechanical behavior of welding in butt joint and T-joint combined geometry. In the investigation, they evaluated a 3D FEM modelling for numerical evaluations. Atabaki et al. [11] made FEA numerical simulation by developing a heat source model to investigate the heat distribution and temperature fields in hybrid laser welding of dissimilar Aluminium alloys series AA5456- AA6061. Traidia et al. [12] carried out a work to establish the geometry of the weld bead and its behavior in a Gas Tungsten Arc Welding of steels by experimental and numerical approach. Heat transfer, mass flow and electro-magnetic fields were solved. The weld pools were solved for the complete penetration depth. The numerical simulation results were validated by the experiments data. Fu et al. [13] made a study on welding sequence and its impact on residual stresses for an octagonal funnel plates. In this study, a three dimensional FEA technique was adopted by using a ABACUS software package and the study helps in identifying the best sequence of operation to optimize the residual stresses. Magalhães et al. [14], made an investigation on the thermal behavior of GTAW process by using highly sophisticated temperature sensors moving along with moving heat source. The investigation also focuses on the inverse technique to evaluate the thermal efficiency with respect to time in GTAW process. The method adopted was highly sensitive, accurate and also economical for estimation of thermal efficiency. Vishwanath et al. [15] made a heat transfer study on the similar basis on friction stir welding of AA6061-AA5056 combinations using ANSYS software package. The study focused on the estimation of heat transfer behavior like temperature field and the fluid flow was neglected as the friction stir welding takes place in solid state.

In the present investigation, the computational numerical simulations are carried out for heat transfer and mass flow behavior in the Gas Tungsten Arc Welding of AA6061 Aluminium alloy plates. Experiments are conducted to take the temperature data and the heat source profiles by three heat inputs and are tabulated. The heat source models obtained at three different heat inputs are used for the computational studies. The heat source profiles are modeled using the Solid EDGE software and called in the ICEM CFD to generate grids. The unstructured grid formations are carried for the heat source model in the ICEM CFD of ANSYS 19.0 versions and grids are generated to the workpiece same as the experimentally used. The Material properties, boundary conditions and heat input parameters are applied in the ANSYS Workbench and solved.

2.0 Experimental Methodology for Validation

Experimental methodology is the real practical investigations that are carried to obtain the certain necessary data's for validating the results obtained from the computational numerical simulation. The experimental investigation helps to have a practical observations on the quality of the welded joints made and once the geometrical profiles are obtained from the different welding techniques from the Heat Affected Zones which are called as heat source models in numerical simulations, the profiles are taken to the numerical simulations by modelling the same profile as obtained during experimentation.

The experimental methodology involves three steps. First step involves job or workpiece preparations where the raw materials are identified for the welding and the identified raw materials are made to cut into the required dimensions. The cut pieces are made milled to obtain good finishing and checked for the dimensional accuracy using the height gauges and Vernier calipers. The machined samples brought to drilling and taping operations for thermocouple mounting and fixing **Fig. 1**. The machined samples are chemically treated with the 50% nitric acid and 50% water solution. Second step involves the measurements and data acquisitions, Temperature data are obtained by paperless temperature recorder by RR Electronics RRE-PR-3500 having high performance visibility of LCD display with multiple displays and provided with data acquisition software where the data's are viewed directly during the experimentations. Temperature distribution data are obtained in different graphical forms as indicated by display and at the same time it can be displayed in the Laptop using

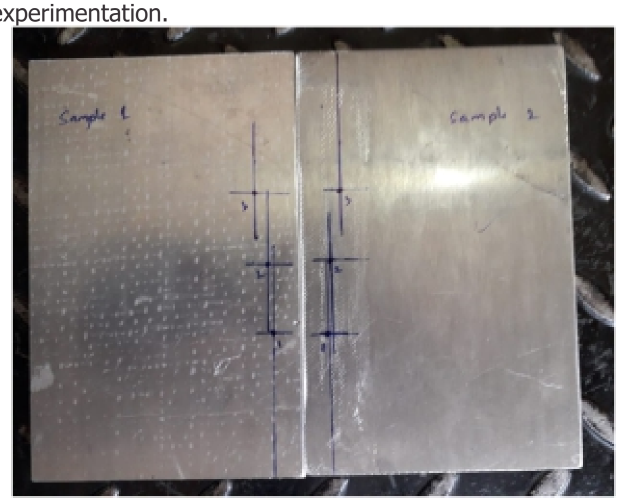

Fig. 1. (a) : Thermocouple locations,

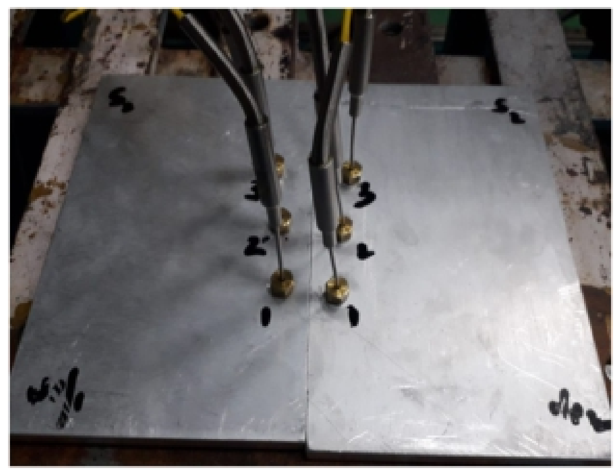

Fig. 1. (b) : Thermocouple fixing to the Samples

Fig. 2 . (a) Fully Automated GTA Welding Machine

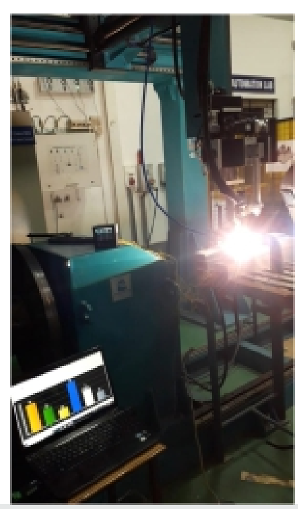

Fig. 2. (b) : GTA Welding with Data Acquisition

USB converter and DAQ software combination. The third step involves the experimentation process, where the experiments are carried with Fully Automated Computer numerically controlled welding machine in order to get the uniform welding profiles for GTAW or TIG welding. The heat source profiles are measured for numerical modeling and simulations, the temperature distribution data's collected for validating the numerical simulation.

The experiments are carried at Centre of Excellence in Welding and Joining, PSG Tech, Coimbatore, Tamilnadu for simple Gas Tungsten Arc Welding of AA6061 Aluminium Alloys by Fully Automated Computer Numerically Controlled welding machine **Fig. 2**. to get the uniform welding profiles. The welding is carried in three different heat inputs to examine the temperature distributions, the weld profile formed and variation of weld profiles at different heat inputs heat inputs

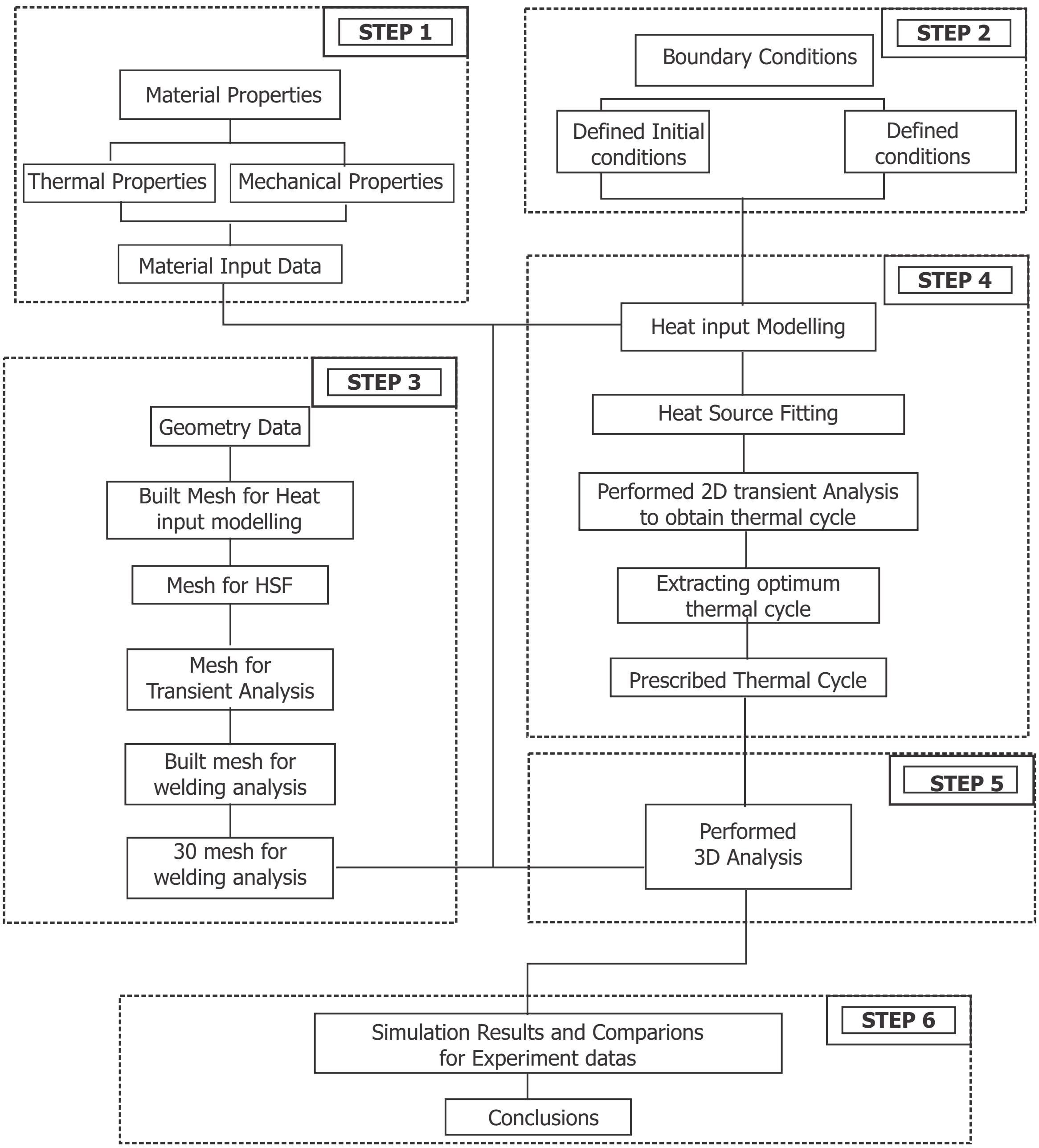

Fig. 3 : Flow chart for the numerical simulation of GTAW

3.45 kJ/mm, 3.86 kJ/mm and 3.97 kJ/mm. In order to carry out the experimentation the AA6061 samples are used having dimension 150mm x 100 mm having 6mm thickness. The welding is carried on the 150mm side with welding speed of 70mm/min.

3.0 Computational Methodology Using Ansys

The block diagram **Fig. 3**, shows the modeling and simulation procedure carried to study the thermal behavior GTAW where heat and mass related issues are investigated through computational approach and solution process for solving the governing equations [15].

Computational Methodology is the very important and considered as the vital part of the present investigation as the research objective is to study the heat transfer and mass flow in different welding process using computational approach. Before doing the computations investigations some experimentation is made to validate the computational numerical investigations made. In order to validate the computational numerical investigations, two important parameters are considered one is the heat source models obtained and the other is temperature distribution curves from the experimentations. The following sessions the brief explains of numerical techniques adopted during the computational investigation.

3.1 Temperature Dependent Material Properties

The computational numerical simulations in the present investigation are a transient heat transfer studies, therefore the thermal properties are not uniform with the time and temperature. A general heat conduction equation is a dependent factor of material thermal properties used and it effects the heat distributions and hence the temperature field in the weld plate. The transient thermal simulation for heat transfer studies helps the researcher to incorporate the thermal properties for the type of the metals been modeled which in turn helps for further simulation. The material used in the numerical simulations of GTAW is AA6061. The thermal Properties of material AA6061 Aluminium Alloy are listed [15] in the following **Table 1**.

1.1 Initial and Boundary conditions

Computational Numerical simulations are the similar type problem solving technique by FEA which requires a mathematical model which is done by obtaining the Governing equation. These governing equations require certain initial and boundary conditions to solve the problems the following are certain initial and boundary conditions described.

Initial conditions: The computational numerical simulations carried for the heat transfer problem is a transient thermal where the different heat input parameters are varying with time but before starting simulations initial conditions need to be specified in the with respect to space and time and is given by,

$$T(x,y,z,0)=f(x,y,z) \quad (1)$$

Boundary conditions: These are the conditions at the different surfaces where the boundaries of the workpiece and the heat input surfaces are exposed to different convective and radiation heat loses. In welding process normally the heat input from a heat source is moving in the weld line and the workpiece is held stationary. It is assumed that the top face where the welding is occurring is with the convective and radiative heat losses and at other faces the heat losses are neglected. In such a situation the Homogeneous Neumann Boundary conditions are more preferable and are written as follows.

$$\text{At } X=\frac{-L}{2} \text{ and } X=\frac{L}{2} \qquad u=0; v=0; w=0; \frac{dH}{dx}=0 \quad (2)$$

$$\text{At } Y=\frac{-W}{2} \text{ and } Y=\frac{W}{2} \qquad u=0; v=0; w=0; \frac{dH}{dy}=0 \quad (3)$$

$$\text{At } Z=D \qquad u=0; v=0; w=0; \frac{dH}{dz}=0 \quad (4)$$

$$\text{At } Z=0 \qquad u=0; v=0; w=0; \frac{dH}{dt}=Q_g(x,y,z,t)\ Q_{cr} \quad (5)$$

Where u, v and w are velocities in X, Y and Z directions. L, W and D are the dimensions of the plate in mm and Q_{cr} is the heat carried away by convection and radiation.

$$Q_{Cr}=Q_{Conv}+Q_{rad} \quad (6)$$

Table 1 : Thermal properties of AA6061

Temperature (^{0}C)	Density (Kg/m^3)	Specific heat (KJ/kg (^{0}C)	Thermal Conductivity (W/m ^{0}C)	Enthalpy (GJ/m^3)
25	2700	0.896	160.2	0.060
37.8	2685	0.945	162	0.096
93.3	2685	0.978	170.8	0.229
148.9	2667	1.004	184.4	0.385
204.4	2657	1.028	192.5	0.540
260	2657	1.052	201	0.726
315.6	2630	1.078	207.3	0.872
371.1	2620	1.104	217.1	1.041
426.7	2602	1.133	223.6	1.222

$$Q_{Cr} = h_{total} A_s (T_s - T_a) \quad (7)$$

$$h_{total} = h_{con} + \varepsilon\sigma(T_s + T_a)(T_s^2 + T_a) \quad (8)$$

Where, A_s and T_s is the surface area and temperature in m^2 and K respectively, T_a is the atmospheric temperature in K, htotal is the combined convective and radiative heat transfer coefficient in $W/m^2 K$

3.3 Modeling and Meshing and Numerical simulations using ANSYS

Modeling and meshing of the heat source model and the work pieces are done before the transient thermal simulations. The modeling is done by suitable Solid edge V19 software for the required dimension of Gaussian distributed hemispherical Heat source model obtained during welding, and the workpiece having dimension 150mm x 100mm x 6mm and is saved in STEP form and it's incorporated in the ICEM CFD 19.0 which is a part of ANSYS Software for meshing, these meshed workpiece models can be directly called into the WORKBENCH whenever the Finite element grid models are required for transient thermal and Fluid flow simulations.

The total number of elements obtained is 62365 and the total number of Nodes formed is 10807 for the heat source model and the total number of elements obtained is 24740 and the total number of Nodes formed is 4748 for the workpiece which will help in obtaining the nodes at the thermocouples locations and the temperature field can be obtained through transient thermal simulations at that nodes..

3.4 Heat Source and Fluid Flow Modeling and Formulations

The mathematical history to carry out the simulation of arc welding process by adapting Finite Volume Method using ANSYS software package is first reviewed. The mathematical equation for the heat distribution to work piece is obtained from basic energy equation and are formulated to the Gaussian distributed hemispherical heat source model. The fluid flow equations are obtained by buoyancy and electromagnetic forces, surface tension, Marangoni stresses. The governing equations of energy and momentum are represented in the following section.

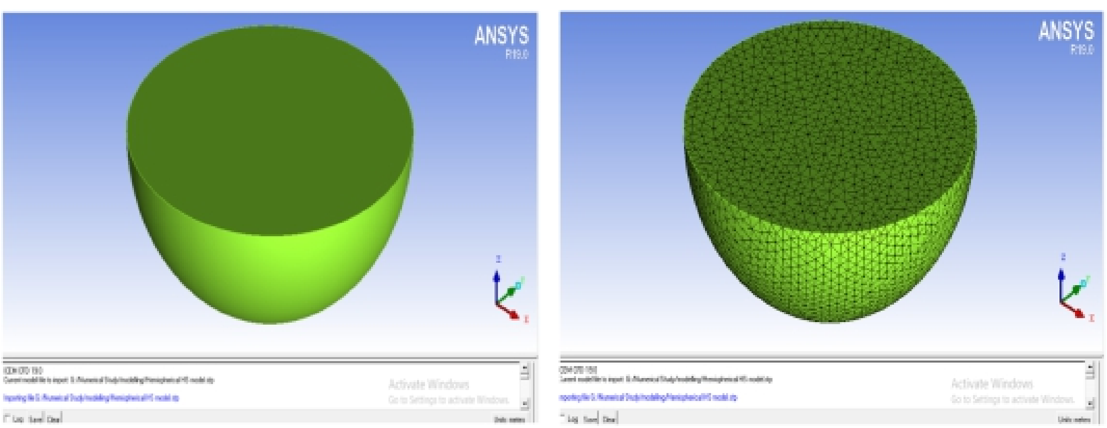

Fig. 4 : 3D modeling and meshing of the Hemispherical heat source model

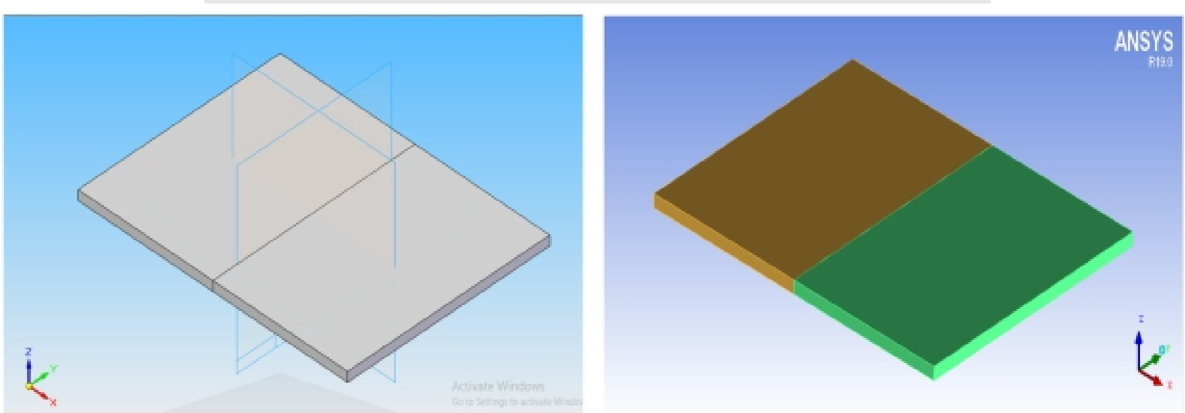

Fig. 5 : 3D modeling and meshing of the Hemispherical heat source model

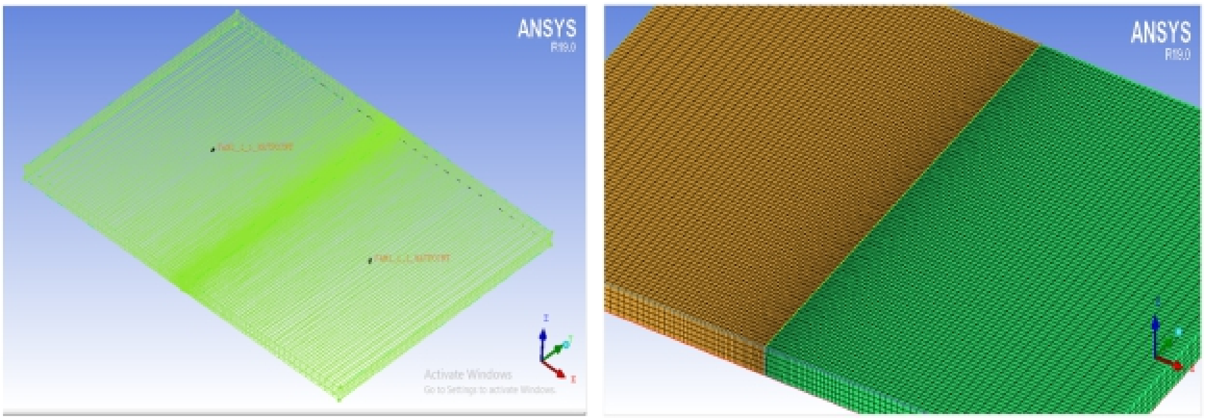

Fig. 6 : 3D modeling and meshing of the Hemispherical heat source model

Continuity Equation

0

$$\frac{\alpha(\rho\mu)}{\alpha x} + \frac{\alpha(\rho v)}{\alpha y} + \frac{\alpha(\rho w)}{\alpha z} = 0 \qquad (9)$$

Energy Equation

$$\nabla.(k\nabla T) - Q_g = \rho C_p \frac{\partial T}{\partial t} - \rho C_p (u) \frac{\partial T}{\partial x} - \rho C_p (v) \frac{\partial T}{\partial y} - \rho C_p (w) \frac{\partial T}{\partial z} \qquad (10)$$

The above equation is in the three dimensional form with moving heat source, Q_g and is the heat generation of the energy equation, this heat source term is taken from the initially developed Three dimensional Gaussian distributed Hemispherical heat source model with the moving heat source. The schematic representation of the hemispherical heat source model is as shown in **Fig. 7**.

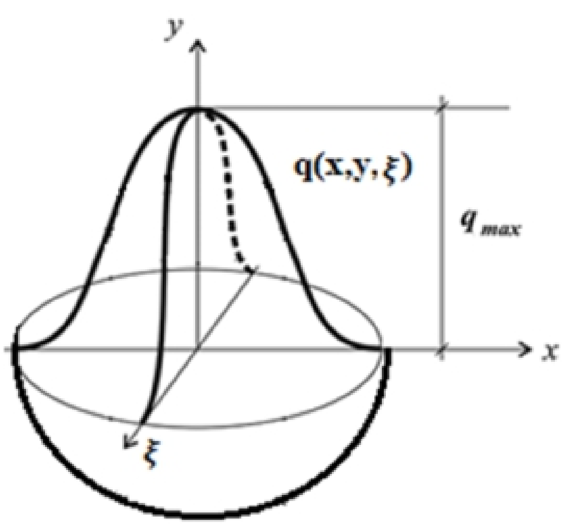

Fig. 7 : Gaussian Distributed Hemispherical heat source model

Three dimensional hemispherical heat source models is an ideal model to understand the volumetric heat flux distribution. If the welding penetration is very less the 2D surface heat flux distributions by Pavelic, Friedman and Krutz studies are sufficient but if the penetration depth is higher 3-D Hemispherical Gaussian distributed heat source model is better compared to disc model. 3-D Hemispherical heat source model is the first heat source model evolved in the three dimensional form as the model is simple in its geometry helps easily to develop a mathematical expression for the heat distribution equation [1].

Heat flux density $q_{x,y},\xi$ distribution for the hemispherical volume is represented as

$$q_{x,y,\xi} = \frac{6\sqrt{3Q}}{c^3\pi\sqrt{\pi}} e^{-3x^2/c^2} e^{-3y^2/c^2} e^{-3\xi^2/c^2} \qquad (11)$$

Where, $q_{x,y},\xi$ is the Heat flux density in W/m^3 and C is the radius of the hemisphere in mm.

Momentum Equation

These momentum equations are the Navier-Stoke equations and represented in x, y and z direction as:

$$\frac{\partial(\rho uu)}{\partial x} + \frac{\partial(\rho vu)}{\partial y} + \frac{\partial(\rho wu)}{\partial z} = \frac{\partial P}{\partial x} + \frac{\partial}{\partial x}\left(\mu \frac{\partial u}{\partial x}\right) + \frac{\partial}{\partial y}\left(\mu \frac{\partial u}{\partial y}\right) + \frac{\partial}{\partial z}\left(\mu \frac{\partial u}{\partial z}\right) + S_x \qquad (12)$$

$$\frac{\partial(\rho vu)}{\partial x} + \frac{\partial(\rho vv)}{\partial y} + \frac{\partial(\rho vw)}{\partial z} = \frac{\partial P}{\partial y} + \frac{\partial}{\partial x}\left(\mu \frac{\partial v}{\partial x}\right) + \frac{\partial}{\partial y}\left(\mu \frac{\partial v}{\partial y}\right) + \frac{\partial}{\partial z}\left(\mu \frac{\partial v}{\partial z}\right) + S_y \qquad (13)$$

$$\frac{\partial(\rho wu)}{\partial x} + \frac{\partial(\rho wv)}{\partial y} + \frac{\partial(\rho ww)}{\partial z} = \frac{\partial P}{\partial z} + \frac{\partial}{\partial x}\left(\mu \frac{\partial w}{\partial x}\right) + \frac{\partial}{\partial y}\left(\mu \frac{\partial w}{\partial y}\right) + \frac{\partial}{\partial z}\left(\mu \frac{\partial w}{\partial z}\right) + S_z \qquad (14)$$

Where, S_x, S_y, S_z are the source term in x, y and z directions.

3.5 FEA simulation of heat transfer study - Temperature contours

FEA simulation is made in this investigation by ANSYS Workbench 19.0 software. The simulation carried for understanding the temperature field to study Heat transfer behavior during the GTAW welding of AA6061 series plates. The heat transfer studies focus on obtaining the temperature contours as a part of heat transfer study to validate the results where the temperature data are obtained during the experimentation. The heat input is given in the numerical simulation as that of experimentation and temperature contours are obtained to understand the heat distributions and is also helps in estimating the heat transfer related parameters like temperature distribution, peak temperature cooling rate.

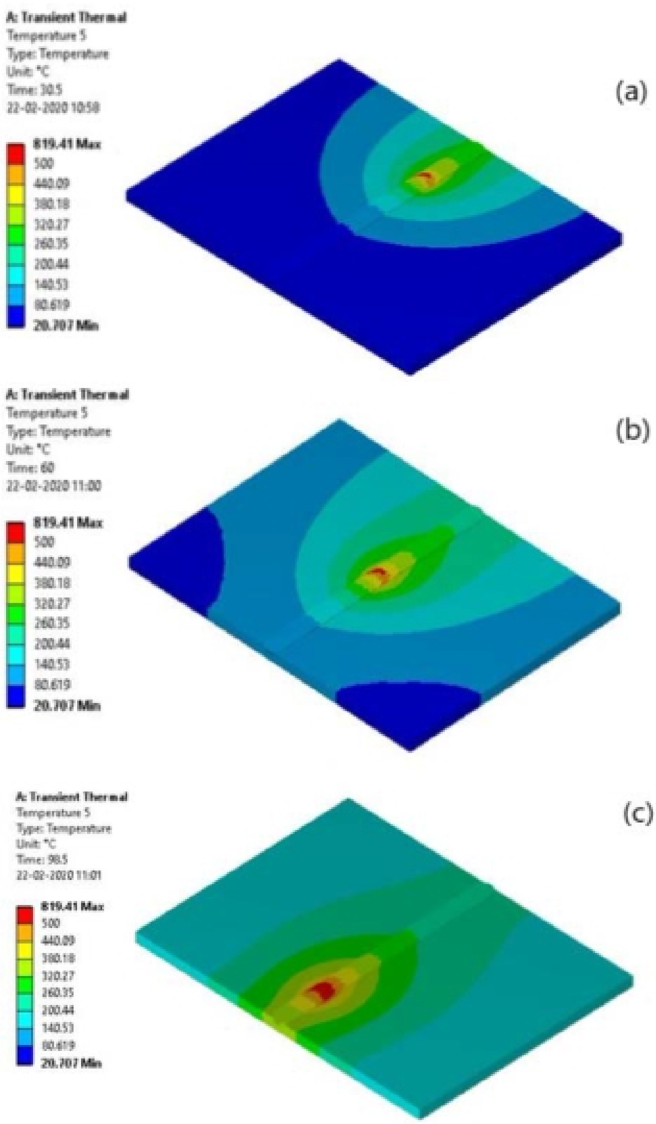

Fig. 8 : Temperature contours of AA6061 plates in GTAW welding

In Gas Tungsten Arc Welding process, numerical simulation is carried by Gaussian distributed hemispherical which is the first 3D model evolved with moving heat source. The transient heat transfer analysis was made in ANSYS Workbench to obtain the temperature distribution curves and validated with experimental data. The temperature contours for the Sample 2 of the GTAW process is as shown in the above **Fig. 8** at every 30 seconds. The welding is carried on the 150mm side with welding speed of 70mm/min during simulation.

3.6 Mass Flow Velocity distribution using ANSYS-FLUENT

Velocity distributions are the important factor in the study of mass flow behavior in welding process. The Flow patterns are carried using the ANSYS Fluent. The velocity field of weld zone is obtained from the geometrical configurations developed during GTAW and is modeled, and simulations are carried out for velocity distribution. **Fig. 9** shows the fluid flow pattern molten zone created due to welding at different heat inputs of 3.45 kJ/mm, 3.86 kJ/mm and 3.97 kJ/mm

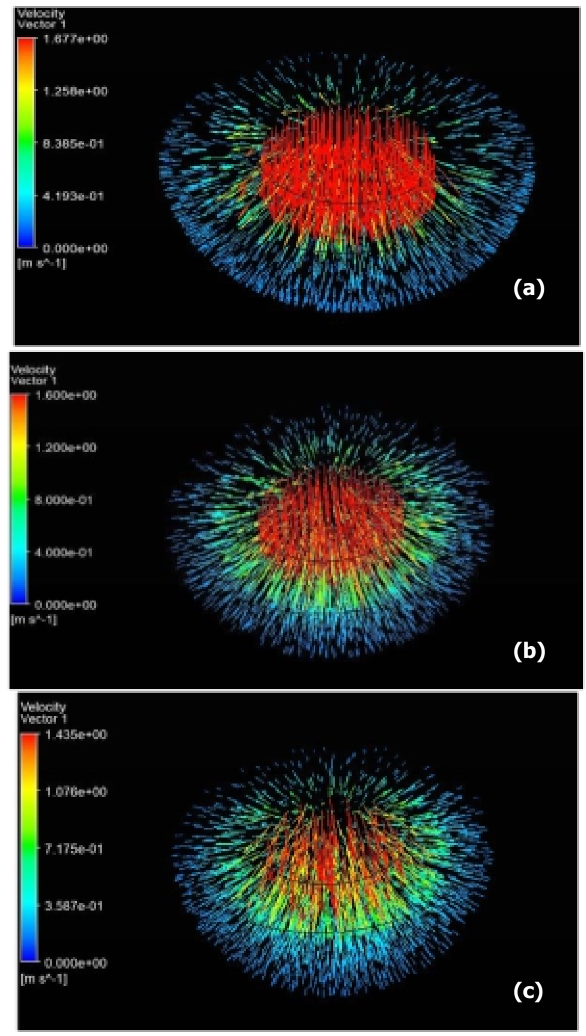

Fig. 9 : Velocity contours during GTAW of AA6061 at different heat inputs

In the velocity distribution, all the three weld pools looks to be similar but the velocities are increasing with the heat input showing more metal flow rates. It was observed that the velocity field in the weld zone increases with the input current. The velocity distribution contours are obtained as velocity vector in meter per seconds. The velocity distribution is generally occurs in the weld zone and hence the studies ate carried for the 3 Dimensional hemispherical heat source model obtained from the During Gas Tungsten Arc Welding at heat inputs 3.45 kJ/mm, 3.86 kJ/mm and 3.97 kJ/mm. In this sections all the three samples are studied for velocity contours using ANSYS Fluent to observe the magnitude of the maximum velocity at different heat inputs and comparative analysis are made. During the fluid flow analysis using ANSYS Fluent only the molten zone obtained during the experimentation are considered as the fluid flow is predominant in this region. The streamlines are looks to be similar in all the heat inputs but the magnitude of the maximum velocity are different. The following figures shows the velocity contours along with the magnitude of the maximum velocity attained with high molten pool at the weld centre and travels towards the rare die with decrease in the magnitude of the velocity indicating less flow velocity at the rare side of the molten pool.

4.0 Results And Discussion

The experimental and the Computational work carried out for GTAW is based on the Gaussian distributed 3D hemispherical heat source profile obtained during GTAW. During GTAW, both the heat transfer and mass flow of molten weld pool are formed by melting of base metal and the non-consumable Tungsten electrode used, and hence, Time-Temperature curve, melting and solidification, peak temperature attained and the cooling rates are estimated through the temperature field obtained, and velocity fields are evaluated through CFD due to different heat input and heat source profiles formed.

4.1 Temperature distribution curves in GTAW

Temperature distribution curves are significant to understand the heat distributions and are obtained at different time steps as heat transfer in weld is transient in nature. The temperature distribution curves are platted for both experimental and numerical simulation results as temperature-time curves. The temperature distribution curves at different thermocouple locations are represented in the following **Fig.10, Fig.11** and **Fig.12**.

The **Fig.10, Fig.11** and **Fig.12** show the comparisons of the Temperature–Time curve for the sample 3 from experimentation and the Numerical simulation results. The thermocouples locations are as discussed in the previous experimental sessions. The six thermocouple T1, T2 and T3 are placed at 10mm, 12mm and 16mm on either side of the AA6061 plates from the weld centre and 50mm, 75mm and 100mm from the side where welding starts. It is also observed that after the Maximum temperature the nature of curve in the experiments looks to be more steeper than the numerically simulated curve indicating the faster cooling rate due to the clamping arrangement made during experimentations which absorbs the heat from the sample plates which is not occur during numerical simulations but the behavior of temperature in experimentation and the numerical simulations are looks to be identical with a very small deviation in all the three locations of the thermocouples.

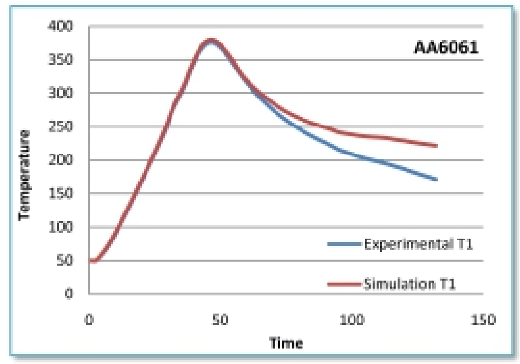

Fig. 10 : Temperature distribution curves for GTAW at 10mm from weld centre

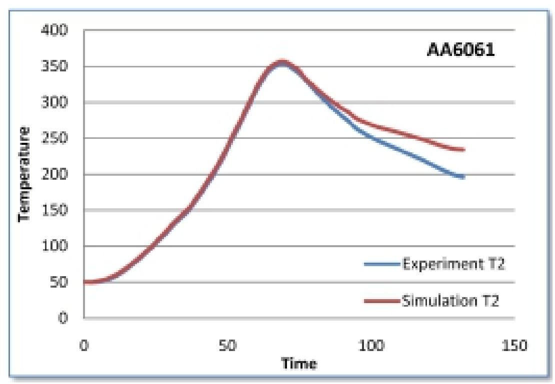

Fig. 11 : Temperature distribution curves for GTAW at 12mm from weld centre

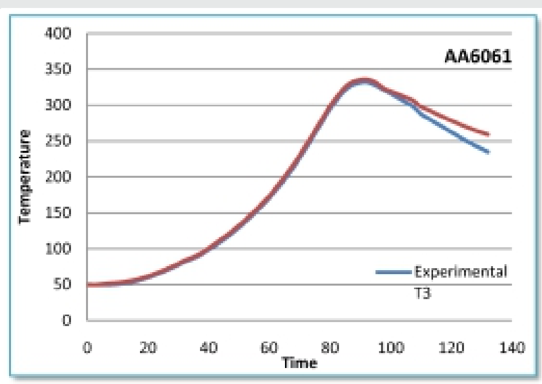

Fig. 12 : Temperature distribution curves for GTAW at 12mm from weld centre

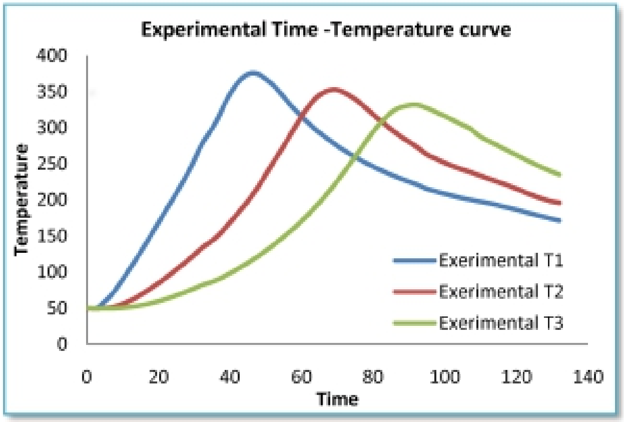

Fig. 13 : Comparison of experimentally obtained Temperature – Time curves for GTAW of AA6061 plate at T1, T2, and T3 from weld centre

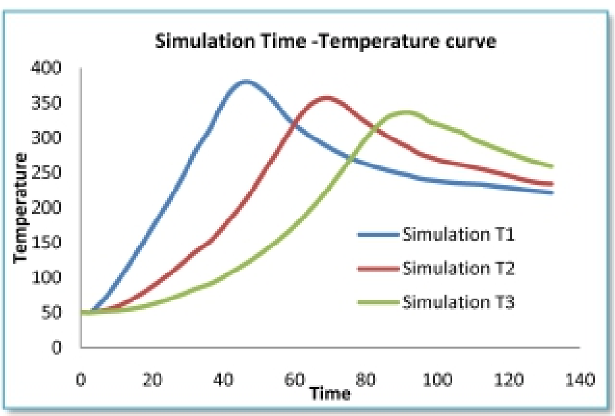

Fig. 14 : Comparison of Numerically simulated Temperature–Time curves for GTAW of AA6061 plate at T1, T2, and T3 from weld centre

It is observed from the above **Fig.13** and **Fig.14** the simulation curves are very similar to experimental data. The Maximum temperature in the numerical simulation and experimentations are 378.2°C and 374.2°C at 43 second at 50mm for the thermocouple placed at 10mm distance from the weld centre, 356.2°C and 352.4°C at 66 second for the thermocouple placed at 75mm and 12mm from the weld centre and 335.92°C and 331.62°C at 86 second for the thermocouple placed at 100mm and 16mm from the weld centre, indicated by **Fig.13** and **Fig.14** gives the Experimental, numerical overall comparisons at all the thermocouple locations at T1, T2, and T3 from weld centre. The above temperature field obtained from the numerical simulations is identical in nature from the experimental temperature field, and hence, the numerical simulation procedure carried out is valid for the given welding process from the heat source profile chosen. This temperature field plays an important role in the study of the heat transfer analysis like estimation of peak temperature, cooling rate, melting and solidifications at the weld centre, and generally these are difficult to obtain through experimental methods.

4.2 Velocity Field at different heat input

The velocity flow patterns are similar in nature but the velocity is varying as the heat input varies due to the molten zone formations. The velocity distributions are considered within the heat source model obtained from the Experimentations for numerical simulations. The following **Fig.15** shows the numerically predicted velocity variations at heat inputs of 3.45 kJ/mm, 3.86 kJ/mm and 3.97 kJ/mm.

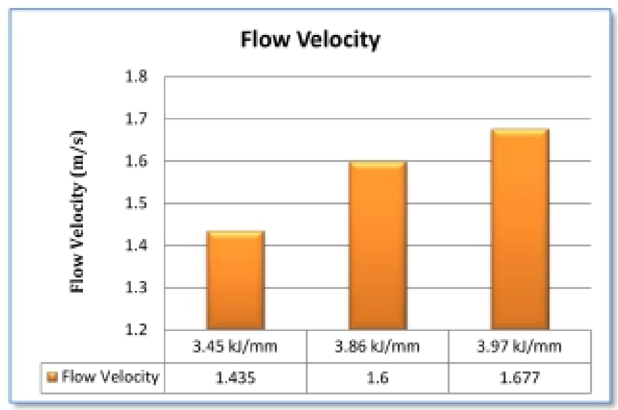

Fig. 15 : Flow velocity at different heat inputs GTAW

It is observed from the above **Fig. 15** that the velocity of the mass flow of the metal in the weld Zone of a GTAW process increases as the heat input increases as its occupies higher peak temperature larger volume of the molten zone is formed. From the above figure, it is seen that there is not much changes in the mass flow rates and the changes are very small and hence the mass flow is not going to play a vital role in the numerical analysis.

5.0 Conclusions

The experiments are carried to obtain the geometrical configuration of weld bead and the temperature field and are called in transient thermal simulations for validations. The data obtained for temperature and the velocity fields from the Computational Numerical simulations provide the information of the research work carried out which uses the experimental data for validation of simulation. The following are some of the critical inferences drawn from analysis of the results obtained from the GTAW process.

1. The Computational investigations made for heat transfer and mass flow in GTAW process is considered based on

geometrical profiles developed during welding called Heat source models based on the experimental observations and used for the numerical simulations to validate the temperature field obtained. The temperature distribution curve obtained from the computational methods shows better agreement with experimental temperature field for the given thermocouple locations indicating the simulation process made can be validated.

2. It is also observed that the size of the heat source models increases with increase in heat input and hence there is a need of extensive investigation on mathematical modelling of geometrical profiles developed for a given heat in put for a given material which plays a very important role in the Thermo -Mechanical analysis of welding which is very much needed to estimate the residual stress distributions, distortions cracks and other defects in welding by computational method.

3. The numerical simulations are carried helps in measuring the temperature field at any locations not only at the surface and but also in molten weld pool during welding. Hence the computational methods are good at measuring the temperature fields and reduce the complexity and expenses of experimental measurements.

4. Velocity distributions are the important factor in the study of mass flow behavior in welding process. The Flow patterns are obtained from the ANSYS Fluent. The mass flow of the molten weld pool is again obtained from the Heat source models. The velocity contours indicates the flow velocity in GTAW is always greater at the weld centre and gradually decreases outwards.

5. Further the study also concludes that the computational method followed by selecting AA6061 Aluminium Alloy for the study to have comfort experimental investigations as it has low melting point compared to steels and the operating temperature can be easily measured and taken for computational investigations.

With the above conclusions the research also leads to different future scope of work in the field of Computational manufacturing Technologies as the heat source models obtained is used for the thermo–mechanical analysis in welding to optimize the processes, avoid defects and strong joints can be obtained by the computational study and can be practically used. The studies can also be conducted for a particular fabrication process like fabrications of boilers, Nuclear panels, storage tanks, large sheets and huge structure and the studied can be carried at the location where welding is performed.

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