Numerical simulation of heat transfer and fluid flow in GTA/Laser hybrid welding

B. Ribic, R. Rai and T. DebRoy

In order to understand the temperature fields, cooling rates and mixing in the weld pool, a comprehensive, three-dimensional heat transfer and fluid flow model is developed and tested by comparing model predictions with two sets of experimental data. The first set of data was taken from the literature. The experiments varied the separation distance between the heat sources for three arc current levels at a constant laser power. The second set of experiments analysed the effect of varying laser power for a constant heat source separation distance. The results demonstrate that the distance between the two heat sources significantly affects the cooling rates. The calculated results showed that the hybrid weld pool was very well mixed with strong convection currents resulting from the interaction between the electromagnetic and Marangoni forces. The calculated and experimental results showed that hybrid welding increases the weld pool width and gap bridgability when compared with laser welding. The weld pool depth in hybrid welding was affected mainly by the characteristics of the laser beam. Hybrid weld pool penetration depth is maximised at an optimal distance between the arc electrode and laser beam. The cooling rate increases significantly when the heat sources are separated beyond a critical distance. At close separation between arc and laser, calculations show that the arc radius must be decreased to achieve the observed weld depths.

Keywords: Hybrid welding, Heat transfer and fluid flow, Laser beam, Gas tungsten arc, Modeling, Cooling rate, Keyhole

Introduction

Hybrid welding involves the joining of metals and alloys by a laser beam and electrical arc. The hybrid welding process incorporates the benefits of both laser and arc welding in order to overcome their individual problems.[1–6] Figure 1 is a schematic of the laser/GTAW hybrid welding process, which depicts the heat source separation distance and arc angle and length. The laser beam, with energy density greater than 10^9 W m^{-2}, provides relatively deep penetration at high welding velocities without the necessity of additional passes.[1–10] The hybrid welding process results in less residual stress and thermal distortion compared to arc welding. Gap tolerance is also increased due to the generation of a wide weld pool.[1–6] Experimental research has also shown that hybrid welding can reduce the propensity of cracking and presence of brittle phases due to relatively lower cooling rates.[11–14] Furthermore, keyhole stability increases, which reduces the amount of porosity due to unstable keyhole collapse.[12,15–18]

The experimentally observed benefits of hybrid welding are due to the interaction of the laser and arc heat sources.[1,2,4–6,19–21] When the arc and laser focal points are within close proximity, the heat sources may interact.[2,5,19,20] The interaction of the two heat sources during hybrid welding is explained by two phenomena. First, arc stability is enhanced due to the introduction of metal vapours into the arc plasma from the laser induced keyhole.[2,5,8–10,19,20,22–33] The metal vapours increase the electrical conductivity of the arc plasma.[2,5,19,20,22,24,26,27,32,33] In addition, the arc contracts, causing an increase in current density.[5,22,24,26,27,34] In the case of introducing copper vapours into a free burning arc, it was observed that the current density can increase by a factor of four.[26] Depending on the separation distance between the heat sources, the arc can bend towards the laser generated keyhole, rooting closer than the physical separation distance.[2,19,20,26]

Beyond a critical separation distance, the arc is unable to bend or root on the keyhole due to the lack of metal vapour introduced to the arc plasma, explaining why the effect decreases as the distance between the two heat sources increases.[2,5,19,20] Chen *et al.*[2] experimentally studied the hybrid welding of AISI 321 stainless steel and observed the laser–arc interaction. They did not accredit the observed effects to any particular phenomena, but described that a particular value of separation between the two heat sources resulted in a relatively small increase in the penetration of the weld pool. Chen

Department of Materials Science and Engineering, The Pennsylvania State University, 115 Steidle Building, University Park, PA, 16802, US
*Corresponding author, email debroy@psu.edu

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Numerical Simulations Of Heat Transfer And Fluid Flow On A Personal Computer

Scott C. Dulebohn

Numerical Simulations Of Heat Transfer And Fluid Flow On A Personal Computer:

Numerical Simulations of Heat Transfer and Fluid Flow on a Personal Computer Susumu Kotake,Kunio Hijikata,1993 This book describes methodologies for performing numerical simulations of transport processes in heat transfer and fluid flow The reader is guided to make the proper selection of simulation techniques and to interpret the acquired results based on the flow physics involved Computer programs which are used to solve heat transfer and fluid flow problems are integrated into the text Illustrative examples of thermo fluid phenomena are provided in every chapter to enhance understanding of the subjects by offering the reader hands on experience of numerical simulations Most of the fundamental transport processes in heat transfer and fluid flow e g heat conduction in a solid body convection heat transfer of a fin laminar and turbulent heat transfer and flow in a duct or tube and boundary layers over a flat plate are covered A strong emphasis is placed on examinations of the thermo fluid phenomena inside a flow passage such as tube and a channel The book contains detailed discussions on the formulation of the boundary conditions which is often the key issue in making successful numerical simulations of the physical phenomena of interest Simulations are carefully designed so that conventional 16 bit personal computers such as IBM PCreg or Apple Macintoshreg can be used Visualizing the simulated results in graphic form plotting charts and line contours of physical variables significantly enhances the reader s understanding of the important transport processes The book is intended as an introductory text for numerical simulations of heat transfer and fluid flow phenomena Description is simple and self contained so that beginners can easily understand the material yet it will also serve as a useful reference work for the practitioner Exercise problems are supplied by which the reader can consolidate knowledge of simulation techniques described and gain further insight in the physical processes of interest The book contains two 3frac12 inch floppy disks each of which stores a complete set of simulation source codes discussed in the text These programs are recorded in ASCII format and can be run either on IBM PCreg or Macintoshreg using QuickBasicreg The programs are well documented within the text as well as in the codes themselves with a number of comment statements This helps the reader understand the flow of program runs and if the reader so wishes modifying the original source codes To facilitate prescription of the physical conditions for simulations these programs run in a highly interactive mode In addition the diskettes contain a number of compiled programs which can be executed without the QuickBasicreg program *Numerical Simulations of Heat Transfer and Fluid Flow on a Personal Computer* Susumu Kotake,Kunio Hijikata,1993 This book describes methodologies for performing numerical simulations of transport processes in heat transfer and fluid flow The reader is guided to make the proper selection of simulation techniques and to interpret the acquired results based on the flow physics involved Computer programs which are used to solve heat transfer and fluid flow problems are integrated into the text Illustrative examples of thermo fluid phenomena are provided in every chapter to enhance understanding of the subjects by offering the reader hands on experience of numerical simulations Most of the

fundamental transport processes in heat transfer and fluid flow e g heat conduction in a solid body convection heat transfer of a fin laminar and turbulent heat transfer and flow in a duct or tube and boundary layers over a flat plate are covered A strong emphasis is placed on examinations of the thermo fluid phenomena inside a flow passage such as tube and a channel The book contains detailed discussions on the formulation of the boundary conditions which is often the key issue in making successful numerical simulations of the physical phenomena of interest Simulations are carefully designed so that conventional 16 bit personal computers such as IBM PC or Apple Macintosh can be used Visualizing the simulated results in graphic form plotting charts and line contours of physical variables significantly enhances the reader s understanding of the important transport processes The book is intended as an introductory text for numerical simulations of heat transfer and fluid flow phenomena Description is simple and self contained so that beginners can easily understand the material yet it will also serve as a useful reference work for the practitioner Exercise problems are supplied by which the reader can consolidate knowledge of simulation techniques described and gain further insight in the physical processes of interest The book contains two 31 2 inch floppy disks each of which stores a complete set of simulation source codes discussed in the text These programs are recorded in ASCII format and can be run either on IBM PC or Macintosh using QuickBasic The programs are well documented within the text as well as in the codes themselves with a number of comment statements This helps the reader understand the flow of program runs and if the reader so wishes modifying the original source codes To facilitate prescription of the physical conditions for simulations these programs run in a highly interactive mode In addition the diskettes contain a number of compiled programs which can be executed without the QuickBasic program

Computational Fluid Dynamics in Industrial Combustion Charles E. Baukal, Jr.,Vladimir Gershtein,Xianming Jimmy Li,2000-10-26 Although many books have been written on computational fluid dynamics CFD and many written on combustion most contain very limited coverage of the combination of CFD and industrial combustion Furthermore most of these books are written at an advanced academic level emphasize theory over practice and provide little help to engineers who need to use CFD for combustion modeling Computational Fluid Dynamics in Industrial Combustion fills this gap in the literature Focusing on topics of interest to the practicing engineer it codifies the many relevant books papers and reports written on this combined subject into a single coherent reference It looks at each topic from a somewhat narrow perspective to see how that topic affects modeling in industrial combustion The editor and his team of expert authors address these topics within three main sections Modeling Techniques The basics of CFD modeling in combustion Industrial Applications Specific applications of CFD in the steel aluminum glass gas turbine and petrochemical industries Advanced Techniques Subjects rarely addressed in other texts including design optimization simulation and visualization Rapid increases in computing power and significant advances in commercial CFD codes have led to a tremendous increase in the application of CFD to industrial combustion Thorough and clearly representing the techniques and issues confronted in industry

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advantages significantly lower by product production To stimulate future research the author includes coverage of hitherto neglected approaches such as that of the Second Law of Thermodynamics pioneered by Bejan and co workers The justification for this is that there is increasing interest in life cycle and sustainable approaches to industrial activity as a whole often involving exergy Second Law analysis Heat exchangers being fundamental components of energy and process systems are both savers and spenders of exergy according to interpretation Photonics Modelling and Design Slawomir Sujecki,2014-12-03 Photonics Modeling and Design delivers a concise introduction to the modeling and design of photonic devices Assuming a general knowledge of photonics and the operating principles of fibre and semiconductor lasers this book Describes the analysis of the light propagation in dielectric media Discusses heat diffusion and carrier transport Applies the presented theory to develop fibre and semiconductor laser models Addresses the propagation of short optical pulses in optical fibres Puts all modeling into practical context with examples of devices currently in development or on the market Providing hands on guidance in the form of MATLAB scripts tips and other downloadable content Photonics Modeling and Design is written for students and professionals interested in modeling photonic devices either for gaining a deeper understanding of the operation or to optimize the design **Convective Heat Transfer** I. Pop,Derek B Ingham,2001-02-23 Interest in studying the phenomena of convective heat and mass transfer between an ambient fluid and a body which is immersed in it stems both from fundamental considerations such as the development of better insights into the nature of the underlying physical processes which take place and from practical considerations such as the fact that these idealised configurations serve as a launching pad formodelling the analogous transfer processes in more realistic physical systems Such idealised geometries also provide a test ground for checking the validity of theoreticalanalyses Consequently an immense research effort has been expended in exploring and understanding the convective heat and mass transfer processes between a fluid and submerged objects of various shapes Among several geometries which have received considerable attention are plates circular and elliptical cylinders and spheres although much information is also available for some other bodies such ascorrugated surfaces or bodies of relatively complicated shapes The book is a unified progress report which captures the spirit of the work in progress in boundary layer heat transfer research and also identifies potential difficulties and areas for further study In addition this work provides new material on convective heat and mass transfer as well as a fresh look at basic methods in heat transfer Extensive references are included in order to stimulate further studies of the problems considered A state of the art picture of boundary layer heat transfer today is presented by listing and commenting also upon the most recent successful efforts and identifying the needs for further research *Applied mechanics reviews* ,1948 **Transport Phenomena in Porous Media II** I. Pop,Derek B Ingham,2002-06-20 Transport phenomena in porous media continues to be a field which attracts intensive research activity This is primarily due to the fact that it plays an important and practical role in a large variety of diverse scientific applications Transport Phenomena in Porous Media II

covers a wide range of the engineering and technological applications including both stable and unstable flows heat and mass transfer porosity and turbulence Transport Phenomena in Porous Media II is the second volume in a series emphasising the fundamentals and applications of research in porous media It contains 16 interrelated chapters of controversial and in some cases conflicting research over a wide range of topics The first volume of this series published in 1998 met with a very favourable reception Transport Phenomena in Porous Media II maintains the original concept including a wide and diverse range of topics whilst providing an up to date summary of recent research in the field by its leading practitioners

Numerical Simulations in Engineering and Science Srinivasa Rao,2018-07-11 Computational science is one of the rapidly growing multidisciplinary fields The high performance computing capabilities are utilized to solve and understand complex problems This book offers a detailed exposition of the numerical methods that are used in engineering and science The chapters are arranged in such a way that the readers will be able to select the topics appropriate to their interest and need The text features a broad array of applications of computational methods to science and technology This book would be an interesting supplement for the practicing engineers scientists and graduate students Computational Aspects of Heat Transfer Benchmark Problems American Society of Mechanical Engineers. Winter Annual Meeting,1993 *Mars* Viorel Badescu,2009-12-07 th th Mars the Red Planet fourth planet from the Sun forever linked with 19 and 20 Century fantasy of a bellicose intelligent Martian civilization The romance and excitement of that fiction remains today even as technologically sophisticated botic orbiters landers and rovers seek to unveil Mars secrets but so far they have yet to find evidence of life The aura of excitement though is justified for another reason Mars is a very special place It is the only planetary surface in the Solar System where humans once free from the bounds of Earth might hope to establish habitable self sufficient colonies Endowed with an insatiable drive focused motivation and a keen sense of ploration and adventure humans will undergo the extremes of physical hardship and danger to push the envelope to do what has not yet been done Because of their very nature there is little doubt that humans will in fact conquer Mars But even earth bound extremes such those experienced by the early polar explorers may seem like a walk in the park compared to future experiences on Mars **Memoirs of Faculty of Technology, Tokyo Metropolitan University** Tōkyō Toritsu Daigaku. Kōgakubu,1992 **Scientific and Technical Aerospace Reports** ,1995 Lists citations with abstracts for aerospace related reports obtained from world wide sources and announces documents that have recently been entered into the NASA Scientific and Technical Information Database

Energy Research Abstracts ,1988 *Computer Modelling of Polymer Processing* E. Andreassen,Å Larsen,E. L. Hinrichsen,1992 The use of computers to numerically analyse polymer processing was first reported as for back as the 1950 s and the first commercial software became available around 20 years ago Much research has been carried out since that time and this report aims to summarise contemporary trends in both commercial and academic research and development An additional indexed section containing several hundred abstracts from the Rapra Polymer Library database provides useful

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