On the Key Technologies of Intelligentized Welding Robot

S.B. Chen

Welding Engineering Institute, Shanghai Jiao Tong University,
Shanghai 200030, P.R. China
sbchen@sjtu.edu.cn

Abstract. This paper addresses on key intelligentized technologies for robotic welding, which contains computer vision technology for recognizing weld seam and starting, locally autonomous guiding and tracking seam, real-time intelligent control of weld penetration, seam forming and welding pool dynamics. A locally autonomous intelligentized welding robot (LAIWR) systems was developed, which could realize detecting and recognizing weld surroundings by visual sensing technology, identifying the initial position of weld seam, autonomously guiding weld torch to the weld starting and tracking the seam, real-time control of pulsed GTAW pool dynamics by vision computing and intelligent strategies.

1 Introduction

At present, the most welding robots serving in practical production still are the teaching and playback type, and can't well meet quality and diversification requirements of welding production because this type of robots don't have adaptive ability to circumstance changes and uncertain disturbances during welding process[1-5]. In practical production, welding conditions are often changing, such as the errors of pre-machining and fitting work-piece would result in differences of gap size and position, the change of work-piece heat conduction and dispersion during welding process would bring on weld distortion and penetration odds. In order to overcome or restrain various uncertain influences on welding quality, it will be an effective approach to develop and improve intelligent technologies for welding robots, such as vision sensing, recognizing welding surroundings, autonomously guiding and tracking seam, and real-time intelligent control of robotic welding process[5-12].

In former researches, although some significant results were obtained in vision sensing, modeling and intelligent control of weld quality and pool dynamics[13-18], these intelligent technologies are still not realized effectively in welding robot systems due to complexity of welding process, real-time and opening limits of robot systems[5].

Therefore, developing intelligentized technology for improving current teaching and playback welding robot is necessary and exigent to satisfy high quality and flexible requirements for welding products and advanced manufacturing uptrend[1-5,12].

T.-J. Tarn et al. (Eds.): Robot. Weld., Intellige. & Automation, LNCIS 362, pp. 105–115, 2007.
springerlink.com

2 The Structure of an Intelligentized Welding Robot Systems

The principle scheme of an intelligentized welding robot systems is shown as Fig.1, Which is consisting of a 6-freedom manipulator and a freedom visual servo unit (VSU) installed on the sixth axis of the robot for turning a dual camera sensor; a welding seam guiding unit (SGU), a seam tracking unit (STU), a welding penetration control unit (PCU), a knowledge data unit (KDU) and a system simulation unit (SSU), all units are dominated by a central control computer (CCC). This combined welding robot system could realize autonomously recognizing weld starting and seam by vision sensing in the local circumstance, guiding robot to the starting, tracking seam, and real-time control of welding pool dynamics and seam forming during pulse GTAW by appropriate intelligentized strategies. It is called the locally autonomous intelligentized welding robot (LAIWR) systems in this paper[20].

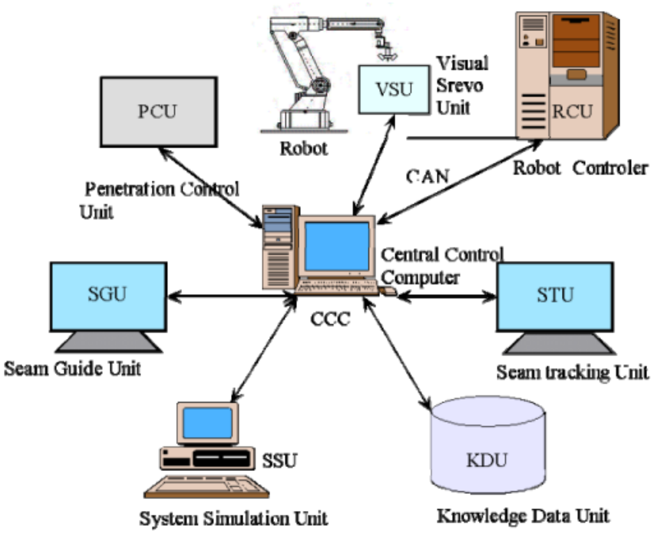


Fig. 1. The hardware structure of the LAIWR systems

3 Key Technologies of Intelligentized Welding Robot Systems

3.1 Recognizing and Guiding of Weld Starting Position for Welding Robot

Realizing welding robot to recognize the weld start position by visual information and autonomously guide the robot to the starting would make the current teaching and playback robot improve its adaptability to the practical varying welding circumstance, it is one of the key technologies for the intelligentized welding robot. In the LAIWR systems, the recognizing and guiding technologies include to acquire the images of work-piece at welding space by visual sensing, to extract the characteristic of weld starting by proper image processing algorithms, to calculate the three dimension coordinate values of the starting point by stereo matching methods, and to guide welding robot moving to the starting point. The recognizing and guiding technology subsystem is shown as Fig.2.

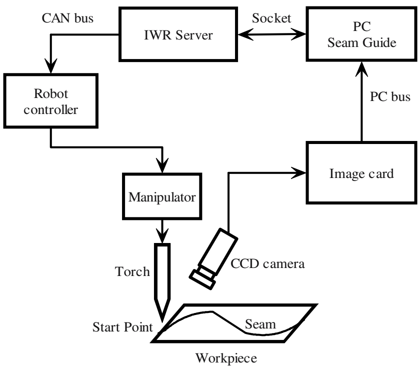


Fig. 2. The recognizing and guiding subsystem based on visual information

The main recognizing and guiding steps of the LAIWR system as following[21]:

1) Image segmentation and region picking-up of weld joint
2) Image processing and recognizing of the weld starting
3) Stereo matching algorithms for weld starting point
4) Autonomously guiding strategy for robot moving to the weld starting

A recognizing and guiding program flow chart is shown as Fig. 3, the detail algorithms and the guiding experiment results on the LAIWR systems are omitted here [21].

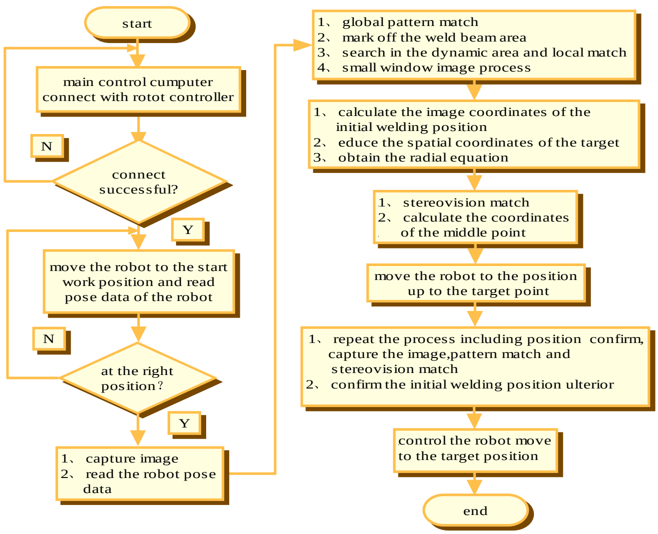


Fig. 3. Recognizing and guiding program flow chart for the LAIWR systems

3.2 Autonomously Programming and Tracking of Robotic Welding Path Based on Servo Vision

Realizing welding robot to recognize weld seam, autonomously programming and real-time tracking of welding path by visual information would make the current teaching and playback robot improve its adaptability to the practical varying welding conditions, such as the error of assemble gap and processing work-piece, distortion and variation of the joint position and size during welding, it is another key technology for the intelligentized welding robot. In the LAIWR systems, it includes recognizing seam curve, autonomously program and track weld path by a servo vision. The principle of welding robotic programming and tracking subsystem with servo vision is shown as Fig.4.

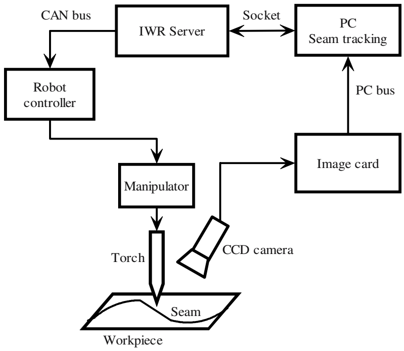


Fig. 4. The welding robotic programming and tracking subsystem with servo vision

Main steps of programming and tracking seam in LAIWR system as following[22]

Using the frontal CCD camera of servo vision sensor, the LAIWR could take the joint image in the front of weld torch. Obtain the deflecting error to the joint and built a correct robotic coordinate value and path for robot tracking weld seam. The main steps is following as:

1) Processing of the joint image to obtain the seam curve
2) Extracting angle and distance deflections of weld seam

The seam and angle deflection are defined as Fig.5, in the image coordinate U-V, the seam deflection is d, and the seam angle deflection is α.

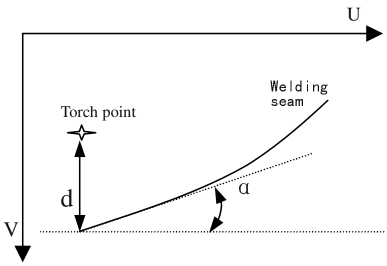


Fig. 5. Definitions of The seam deflection and angle

3) Detecting the end of weld joint

In order to obtain the curve coordinates of a whole complete seam, it is necessary to detect the end of weld joint by the seam image. An image of the seam end is shown as Fig 6, which is the junction of three lines in the processing image of the weld joint.

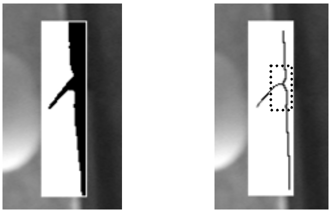
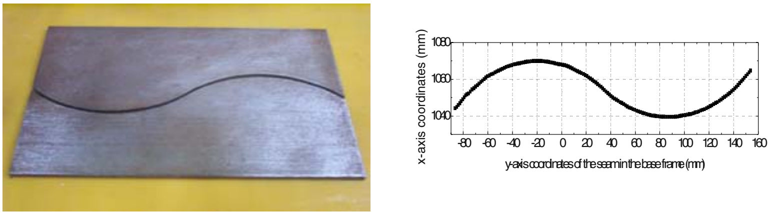


Fig. 6. Processing images of the weld joint

4) Control strategy for robot to track seam curve coordinates

The detail algorithms of programming and tracking seam for LAIWR systems are omitted.

An experiment result of autonomously programming welding robotic path by servo vision is shown as Fig.7.



(a) S shape seam workpiece (b) Robotic programming and tracking curve

Fig. 7. Experiment of robotic programming and tracking path by servo vision

3.3 Real-Time Control of Weld Pool and Seam Forming During Robotic Welding

Realizing real-time control of dynamics of welding pool and seam forming is one of most crucial technologies for robotic welding quality. At present, almost teaching playback welding robot is non real-time control of dynamics of welding pool. In the LAIWR system, a real-time control subsystem as Fig.8 was developed for dynamical process of robotic welding.

(1) Adaptive neural PID controller for real-time control of robotic welding

In the LAIWR systems, an adaptive neural PID controller is developed for real-time control of dynamical pool and fore seam during robotic welding. Control, the controller

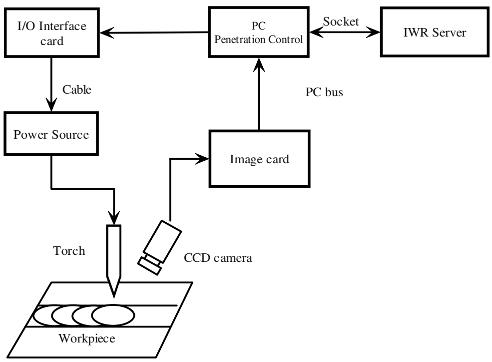


Fig. 8. Real-time control subsystem for dynamical process of robotic welding

framework is showing as Fig.9, which includes common PID regulator, learning algorithms, neural networks NN1 and NN2 for modeling welding dynamics and modifying PID parameters. The controller algorithms are omitted here[20].

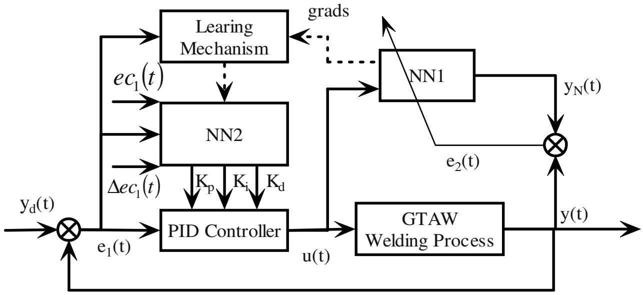
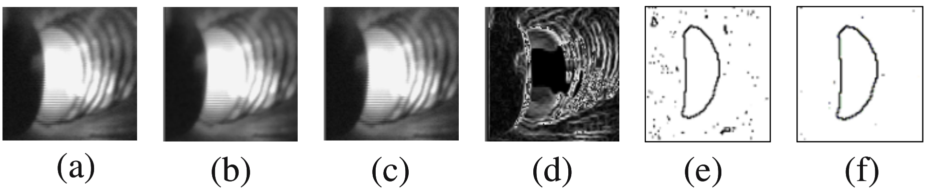


Fig. 9. The framework of adaptive neural PID controller for robotic welding process

(2) Image processing and feature acquiring of weld pool during robotic welding

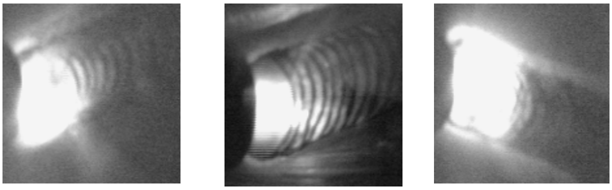
The controlled welding processing and results on the LAIWR systems are shown as Fig.10, it is showing the image processing results of the pool during robotic welding. The details are omitted here[19].



(a) Original (b) Median filter (c) Image reinforcing (d) Edge detecting (e) Profile extracting (f) Filtering

Fig. 10. The results of Al alloy pool image processing during robotic welding

In the robotic welding, the image shape would be changed with seam curve and robot motion direction. The Fig.11 is shown Al alloy pool images in three direction of the S shape seam during robotic welding. The corresponding image processing algorithms were developed in LAIWR systems[20], and here it is omitted.



a) The left rear direction b) The positive rear direction c) The right rear direction

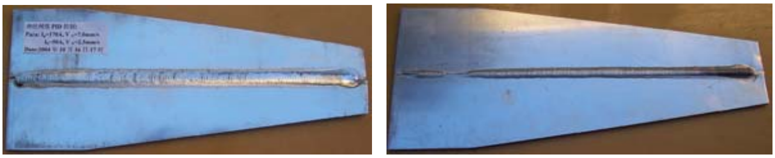
Fig. 11. Al alloy pool images in three direction of the S shape seam during robotic welding

(3) Real-time control experiment during robotic welding[20]

Using the characteristic information of the welding pool, the closed loop feedback control in LAIWR systems was structured and real-time control of dynamic welding process was realized. The experiments of the constant technical parameters, i.e. without the loop feedback control, and simple PID control scheme were conducted for comparing with the designed adaptive neural PID controller in this paper, the compared results is showing that the adaptive neural PID controller in the LAIWR systems is effective for real-time control of weld pool dynamics and fine seam formation during Al alloy pulse GTAW, the details are omitted here. The Fig.12 and Fig.13 are showing the controlled welding results on the LAIWR systems. The trapezoid and dumbbell workpiece are designed to simulate the different changes of heat conduction and the effectiveness of the controller during robotic welding process. The controlled results are showing that the desired seam width, 7.6mm for trapezoid workpiece, and 8.0mm for dumbbell workpiece, are maintained steadily by the peak current regulation during pulse GTAW on the LAIWR systems.

3.4 Knowledge Extracting and Modeling of Dynamical Welding Process

As is well known, the traditional welding is a typical handwork operations, which mainly depends on the welder's skills, due to the highly complexity in welding process. In the intelligentized robotic welding systems, the knowledge model on welding process is a technical focus or key for dominating welding robot system. Some methods of knowledge acquisition and modeling by rough set, fuzzy set and neural network theory have been developed for welding dynamics[5,6,23], here it is omitted.



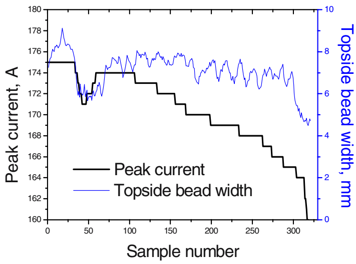
Topside Backside

(a) Trapezoid workpiece

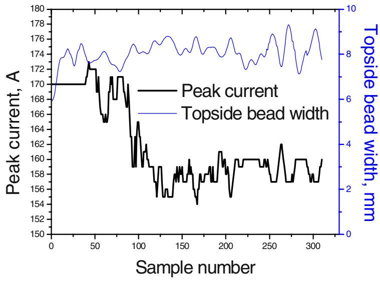
Topside Backside

(b) Dumbbell workpiece

Fig. 12. The workpiece pictures of adaptive neural PID controlled welding on the LAIWR



(a) Trapezoid workpiece



(b) Dumbbell workpiece

Fig. 13. Adaptive neural PID controlled curves of Al alloy welding process on the LAIWR

4 The Intelligent Structure of Intelligentized Welding Robot Systems

Based on analysis on key technologies and functions of the systems like the LAIWR systems in Fig.1 as the above, a hierarchical intelligent structure framework is developed for an intelligentized welding robot systems as Fig.14 [5,20], which is divided into a five-level framework, which includes the executing level, the management level, the coordinator level, the proxy level, and the communication level. The framework can realize to search weld starting position, guide robot reaching the starting, tracking seam and correct deflections, control proper welding penetration and fine forming alike to a skilled welder's operation during welding process.

5 Conclusions

The key intelligentized welding techniques for robot systems include vision sensing for recognizing weld starting, guiding and tracking weld seam, programming path, pose and welding parameters, knowledge modeling and intelligent real-time control of welding dynamics, dominating intelligentized robotic systems, and so on.

This paper has shown a primary intelligentized welding robot systems, so-called LAIWR systems, which realizes some key intelligentized technologies of welding robot system. These intelligentized technologies would be an important foundation for developing new-type intelligent welding robot in the future.

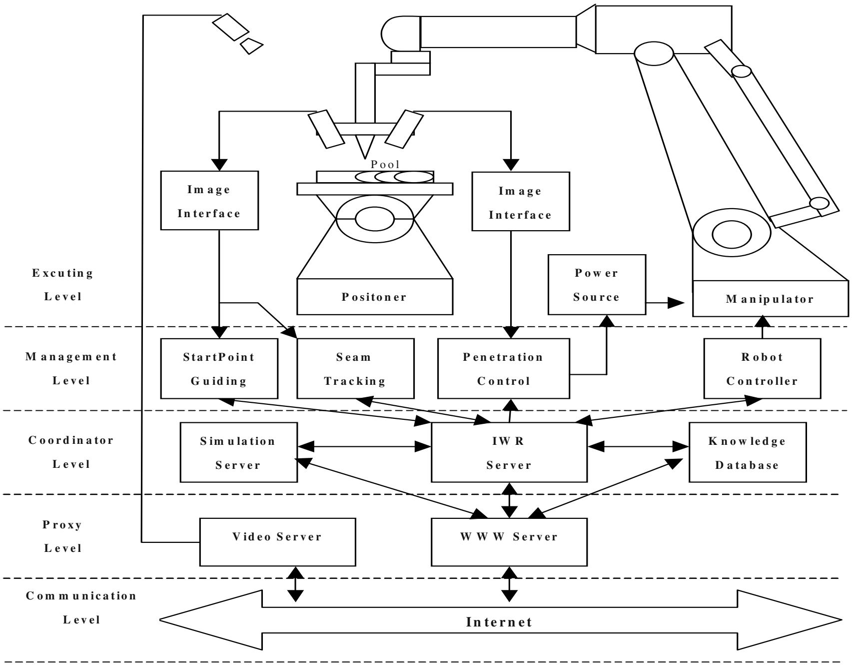


Fig. 14. A hierarchical intelligent structure framework of intelligentized welding systems

Acknowledgment

This work was supported by the National Natural Science Foundation under Grant No. 50575144, 60474036, and supported by Key Foundation Program of Shanghai Sciences & Technology Committee under Grant No. 06JC14036. The author wish to acknowledge the relative study works finished by Dr. Chen Wenjie, Dr. Zhou Lv, Dr. Chen Xizhang, Dr. Zhu Zhenyou and Mr. Lang Yuyou.

References

1. Trailer, Manufacturer Depends on Robotic Welding to Boast Production. Welding Journal. 1995, 74(7): 49-51
2. U. Dilthey, L. Stein. Robot System for Arc Welding—Current Position and Future Trends. Welding & Cutting. 1992, (8): E150-E152
3. J. L. Pan, " A survey of welding sciences in 21th century." Proceeding of 9th Chinese Welding Conference, Tianjun, China, Oct. 1999, (1): D-001-D-017
4. K. P. Valavanis, G. N., Saridis, Intelligent Robotics System: Theory, Design and Applications. Boston, 1992: 12-18
5. *S. B. Chen*, et al., 2004. "Intelligentlized technologies for robotic welding", Series Lecture Notes in Control and Information Sciences, vol. 299: 123-143
6. Chen Shanben, et al., 2003, "On intelligentized technologies for modern welding manufacturing," Chinese Journal of Mechanical Engineering, vol.16, No.4, pp367-370
7. R.J. Beatlie, S.K. Cheng and P.S. Logue. The Use of Vision Sensors in Multipass Welding Applications. Welding Journal. 1988, Vol. 67(11): pp28-33
8. Zh.Y.Zhu, T.Lin, Y.J.Piao, *S.B.Chen*, Recognition of the initial position of the weld based on the image pattern match technology. The International Journal of Advanced Manufacturing Technology, vol.26:784-788, 2005
9. S.B. Chen, X.Z. Chen, J.Q. Li, T. Lin, 2005, "Acquisition of Welding Seam Space Position Information for Arc Welding Robot Based on Vision," Journal of Intelligent & Robotic Systems, vol.43, pp77-97.
10. J.W. Kim and S.J. Na. A Self-Organizing Fuzzy Control Approach to Arc Sensor for Weld Joint Tracking in Gas Metal Arc Welding of Butt Joints. Welding Journal. 1993, Vol. 72(1): pp60s-66s
11. Y. Suga and M. Naruse. Application of Neural Network to Visual Sensing of Weld Line and Automatic Tracking in Robot Welding. Welding in the World. 1994, 34: pp275-284
12. S. B Chen, Y. Zhang, T. Qiu, T Lin., 2003, "Robotic Welding Systems with Vision Sensing and Self-learning Neuron Control of Arc Weld Dynamic Process", Journal of Intelligent and Robotic Systems, vol.36, No.2, pp191-208.
13. S. B. Chen, Y. J. Lou, L. Wu and D.B. Zhao , Intelligent Methodology for Sensing , Modeling and Control of Pulsed GTAW :PART1—Band-on-Plate Welding, Welding Journal, 2000, 79(6):151s-163s
14. S.B. Chen, D. B. Zhao, L. Wu and Y. J. Lou, Intelligent Methodology for Sensing , Modeling and Control of Pulsed GTAW :PART2—Butt Joint Welding, Welding Journal, 2000, 79(6):164s-174s
15. R.W. Richardson and D.A. Gutow. Coaxial Arc Weld Pool Viewing for Process Monitoring and Control. Welding Journal. 1984. 63(3): 43-50
16. J J Wang, T Lin, Shanben Chen, 2005,"Obtaining of weld pool vision information during aluminum alloy TIG welding," International Journal of Advanced manufacturing technology, vol.26:219-227, 2005
17. R. Kovacevic, Y.M. Zhang and L.Li. Monitoring of Weld Joint Penetration Based on Weld Pool Geometrical Appearance. Welding Journal. 1996, Vol. 75(10): pp317s-329s
18. T.G. Lim and H.S. Cho. Estimation of Weld Pool Sizes in GMA Welding Process Using Neural Networks. Journal of Systems and Control Engineering. 1993, Vol. 207(1): pp15-26
19. D. B. Zhao, S. B. Chen, L.Wu, and Q. Chen., 2001, "Intelligent Control for the Double-sided Shape of the Weld Pool in Pulsed GTAW with Wire Filler," Welding Journal, vol.80, No.11, pp253s-260s

20. W. J. Chen, “Research on Local Autonomous Intelligent Welding Robot System and its Remote Control,” Doctoral Dissertation Shanghai Jiao Tong University, 2004.
21. Zh.Y.Zhu, “Research on Welding Robot Recognizing and Guiding of the Initial Welding Position with Visual Method,” Doctoral Dissertation Shanghai Jiao Tong University, 2004.
22. Lv. Zhou, “Vision-based Autonomous Programming methods of welding robotic path,” Doctoral Dissertation Shanghai Jiao Tong University, 2006.
23. B. Wang, S. B. Chen, J. J. Wang, 2005, ”Rough set based knowledge modeling for the aluminium alloy pulsed GTAW process,” International Journal of Advanced Manufacturing Technology, vol. 25 (9-10): 902-908.