연구논문

적외선 카메라를 이용한 용접비드를 제어하기 위한 알고리즘 개발

김일수* · 박창언* · 손준식** · 박순영*** · 정영재** · Y. Prasad****

*목포대학교 기계공학과
**목포대학교 기계공학과 대학원
***목포대학교 전자공학과
****퀸슬레드 공과대학교 기계공학과

Development of an Algorithm for Controlling Welding Bead Using Infrared Thermography

Ill-Soo Kim*, Chang-Eun Park*, Joon-Sik Son**, Soon-Young Park***,
Young-Jae Jeong** and Yarlagadda Prasad****

* Dept. of Mechanical Engineering, Mokpo National University, Mokpo 534-729, Korea
** Graduate School, Dept. of Mechanical Engineering, Mokpo National University, Mokpo 534-729, Korea
*** Dept. of Electronics Engineering, Mokpo National University, Mokpo 534-729, Korea
**** Dept. of School of Mechanical, Manufacturing and Medical Engineering, Queensland University of Techology, Brisbane 4001, Australia

Abstract

Dynamic monitoring of weld pool formation and seam deviations using infrared vision is described in this paper. Isothermal contours representing heat dissipation characteristics during the process of arc welding were analysed and processed using imaging techniques. Maximum bead width and penetration were recorded and the geometric position in relation to the welding seam was measured at each sampling point. Deviations from the desired bead geometry and welding path were sensed and their thermographic representations were digitised and subsequently identified. Evidence suggested that infrared thermography can be utilized to compensate for inaccuracies encountered in real-time during robotic arc welding.

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Key Words : Robotic arc welding, Infrared thermography, Beed geometry, Adaptively control

1. INTRODUCTION

The robotic arc welding is widely employed in the fabrication industry for increasing productivity and enhancing product quality by its high processing speed, accuracy and repeatability. Preprogramming techniques have proved to be inadequate in taking into consideration of the component distortion, due to heat imperfections and seam misalignment which can take place during the welding process. For full automation and adaptive control of the welding process and adaptively control, sensors are needed to monitor the process output in real-time and feedback the generated information to the controller so that process parameters are adjusted accordingly and in-process variations are compensated[1]. These variations can be either in the weld pool shape and size, weld seam, or both.

Tactile sensors have been employed for seam tracking and weld bead penetration control. Even if these are simple to use, their major

limitation lies with their inherent inflexibility and wear characteristics that can give rise to measurement inaccuracies[2,3].

On the other hand, non-contact type sensing is preferable, but the cost associated with the sophisticated system constrains their extensive applications. Contact sensor is utilized to intercept the area of sight, while non-contact sensor is employed to extract information from the welding scene regarding seam positioning and the unfused zone area[4]. Control is performed in real-time and an adaptive manner via an integrated microprocessor capable of taking appropriate corrective action and ensuring that the welding head follows the seam path and deposits the optimum amount of filler material to fuse the joint. A number of variations of systems based on this principle exist, most of which have been miniaturized and made robust over the years[5]. For sensors incorporated within the welding torch or attached to the robotic manipulator, an ability to withstand the harsh welding environment is a major prerequisite. In general, remote sensing techniques are currently under considerable flux and constitute the preferred means for dynamically detecting welding process variations.

Accumulated information at each point is employed to compensate for deficiencies including incomplete penetration and lack of side wall fusion. A system of this type that employs infrared thermography principles and computer imaging techniques has been implemented in real-time monitoring of the robotic arc welding process[6].

Infrared thermography is finding increasing application in the area of non-destructive testing and evaluation as well as in condition monitoring of plant equipment and facilities. Temperature differences down to 0.1℃ can be monitored with today's thermo-electrically cooled infrared scanners. Thermal signatures can be stored on video tapes or on other forms of permanent records including computer disk and photographs.

However, this sophisticated technique is expensive, and this is the only drawback to its wide utilization in industry. It is believed that the more the laboratory applications are researched and developed, the more possibilities for industry implementations may be found.

In the robotic arc welding, infrared thermography has been used to monitor weld quality and the bond strength of resistance welded electrical components in real-time. The system employed[7] was integrated with a microprocessor which compared the measured data against stored models of acceptable weld thermal signatures. Another example is that of monitoring the on-line weld quality of electrical switches used in automobile air bag components. Information related to tensile strength of the weld was extracted from the temperature profiles and heat distribution areas. Infrared thermography has also been used to assess the integrity of critical fusion welds in industries such as air craft and petrochemical[8,9].

Preliminary investigations[9,10] using infrared thermography for welding process status information showed that variations in process parameters produce changes in surface temperature distributions on the plates being welded. During these works, front side scanning infrared camera was used to monitor molten pool and surface temperature distributions during the welding. Process parameters were varied to alter the bead penetration, and corresponding changes in the temperature distribution were recorded. It was established that a linear relationship between bead width and infrared image profile width exists. Additionally, the bead penetration was exponentially correlated to the area under the measured surface temperature profile taken at the centre-line of the molten metal pool[11]. Such findings clearly indicate that the above mentioned information from the surface

temperature of plates being welded can be utilized to control the bead penetration and bead width in real-time. A recent study[6] revealed that by measuring the amount of visible and near infrared emitted from the rear of the weld joint, bead penetration over a range of process parameters can be controlled. The system employed proved to be sensitive enough to employ fibre-optics for transmitting the light from the weld to the sensor. The fibre-optics technology helped the facilitation of welding assemblies with limited access to the underside of the weld is most suited to relatively small diameter tubes. This may be an expensive application but it can be seen as a tool for ensuring specification compliance and minimizing the amount of rework needed, especially on critical and valuable components[12].

The above mentioned techniques have substantially advanced the concept of remote monitoring of bead penetration during the robotic arc welding using infrared sensing, but make no reference to the technique's additional potential capability for seam tracking. In other words, the studies document only the capacity of the emerged technology to accommodate deficiencies related to acceptable penetration variations in real-time. While the correct weld volume deposition is necessary to fuse the joint, its correct placement on the joint that is equally desirable in order to allow quality to be built into the product rather than inspected into it[13]. Although there exists a plethora of seam tracking systems that can be used in conjunction with infrared thermography to complement the seam following capabilities of these systems by controlling bead penetration, it would be more advantageous to fully explore the potential of a single system to control both tasks.

The primary purpose of this paper is to obtain the thermal profile characteristics, to calculate the bead geometry using image analysis techniques and to finally relate the surface temperature distribution of the welded part to the bead width and bead height for development of a new algorithm in order to control bead geometry and seam tracking.

2. EXPERIMENTAL PROCEDURE

The experimental materials were 200×75×12mm mild steel AS 1,204 plates with composition of C 0.25 %, Si 0.4 % and P 0.04 % on which welds were laid adopting the bead-on-plate technique. To optimize the arc welding process, two samples were taken for observation after discarding 50 mm on each side to eliminate the end effects, and both surfaces were cleaned to eliminate any dirt and oxides. The selection of the welding electrode wire was based principally upon matching the mechanical properties and physical characteristics of the base metal, weld size, and existing electrode inventory. Steel wires with diameters of 1.2(mm) with composition of C 0.07-0.15 %, Mn 1.00-1.50 %, Si 0.60-0.85 %, S 0.035 % max, P 0.025 % max and Cu 0.5 % max, were employed as welding consumables. These experimental results were employed to investigate the relationship between the thermal images produced by infrared thermography and bead geometry (bead width and bead height) in order to achieve an adaptive welding process.

The experimental setup was composed of the welding power source by Lincoln arc welding, Hitachi process robot and AGA thermovision 680 system[14]. An automatic wire feeding unit was employed to provide variable wire feed rates, according to arc current level employed. A six axis robotic manipulator was utilized to provide the process speed and welding direction. The robotic and welding controller was interfaced with the welding power source with an adjustable range of output current between 50-350 Amps and an adjustable range of output voltage between 16-36 Volts. A microcomputer was employed to address the robotic arc welding controller and to access its menu containing combinations of process

parameters to achieve the desired quality output. The schematic diagram of the experimental setup employed is illustrated in Fig. 1.

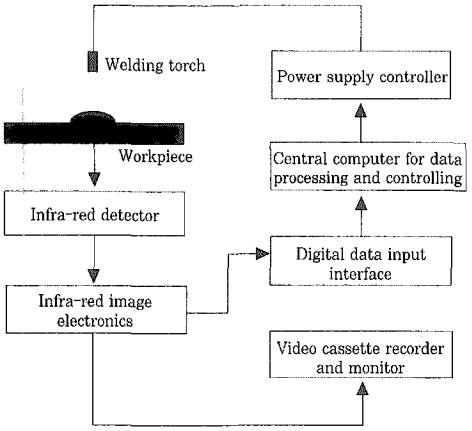


Fig. 1 The schematic diagram of the experiment.

A solid electronics cooled infrared vision camera was employed to convert the invisible infrared given off during welding into equivalent electronic video signals which were then amplified and transferred to the display unit during the welding. The unit was positioned away from, but directly in view of, the rear of the weld steel plates to be welded an interfaced with the same microprocessor as the robotic welding controller through the video output connection. The output was fed to an image frame grabber and after being digitised it was processed using an image analysis software package. The scanning rate of the camera was 30 frames per second and computer image sampling and storage rate was 5 frames per second. Digitised frames were stored in a C.D. erasable/rewritable laser facility for analysis and processing. During the welding, the planner position coordinates of the welding torch in relation to the plate surface were also recovered.

After each welding run, test pieces were sectioned and metallographically examined. Polishing and etching of the welding zone revealed bead dimensions, which were recorded using machine vision facilities. Fig. 2 illustrates measurements of bead width and height taken from the metallographic weld samples. Measurements of bead width and height were performed after welding, using a standard metallographic technique.

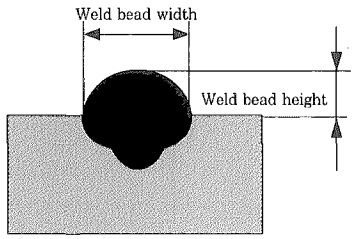
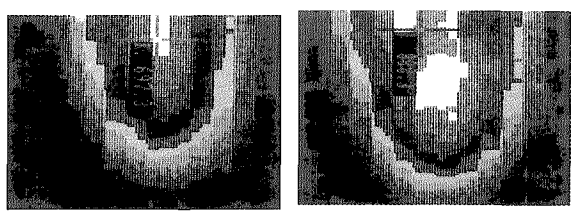


Fig. 2 Metallographic weld sample showing measurements of bead width and bead height.

3. RESULTS AND DISCUSSION

Fig. 3 depicts the temperature distribution obtained during the arc welding process for two welds of varying arc current. As shown in Fig. 3, there are identifiable changes in the surface temperature distribution. Fig. 4 shows temperature versus distance from the thermal images to calculate the width of the temperature



(a) Arc current 150 A (b) Arc current 240 A

Fig. 3 Temperature distribution.

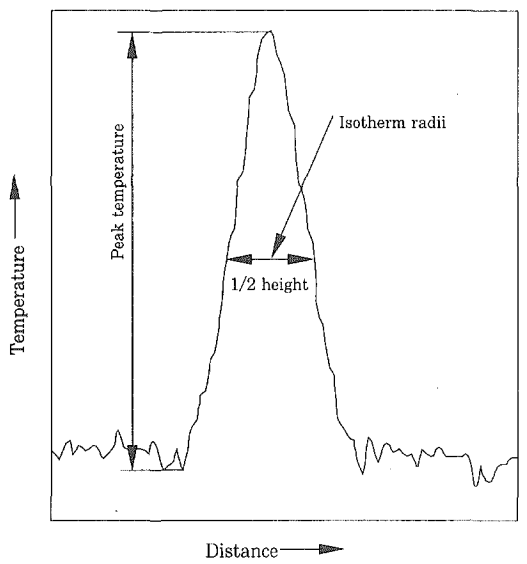


Fig. 4 Diagram showing thermal scan characteristics used.

peak by measuring the profile width at the temperature midway between the peak and background temperature, its unit is called an isotherm unit[14].

Different arc current were employed to produce the variation in weld bead dimensions. Fig. 5 depicts arc current versus isothermradii for 5 mm and 10 mm thickness measured using computer imaging analysis. As shown in Fig. 5,there is a linear relationship between arc current and isotherm radii. Results relating arc current to bead width and height are illustrated in Figs.
6 and 7 for 5 mm and 10 mm thickness respectively.

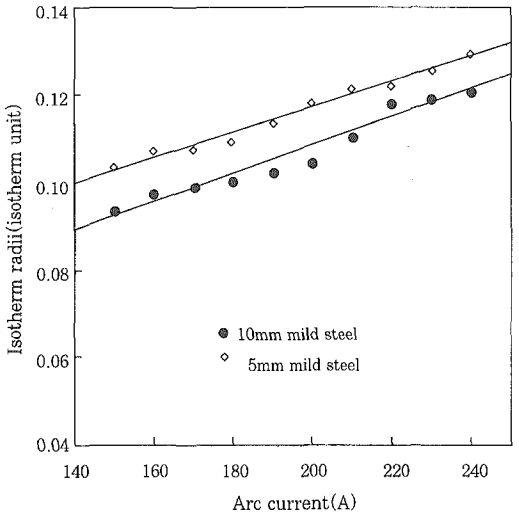


Fig. 5 Arc current versus isotherm radii.

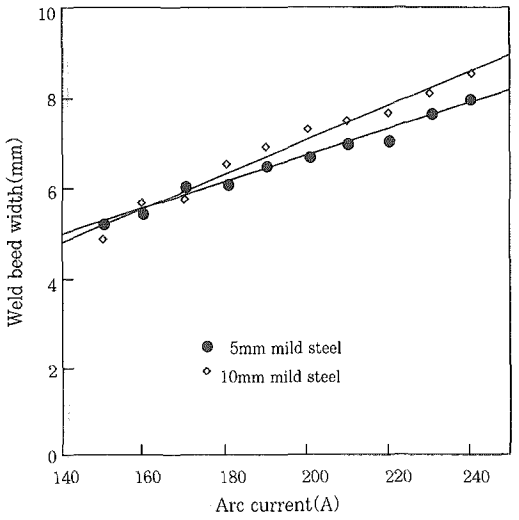


Fig. 6 Arc current versus weld bead width.

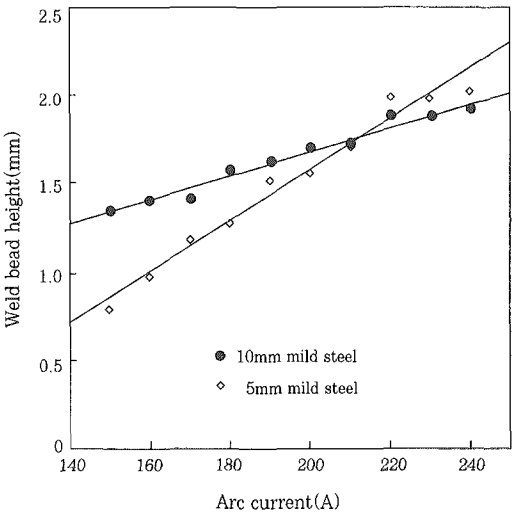


Fig. 7 Arc current versus weld bead height.

It is evident that a linear relationship existed between output parameters and the welding current variation when primary process parameters such as welding voltage and welding speed were kept constant. The thermographic profile measurements of the same welds are shown in Figs. 8 and 9. Here, output parameters are plotted against the isotherm radii measured for 5 mm and 10 mm thickness of mild steel specimens respectively. A linear relationships obtained suggested that adaptive control of bead shape and size can be achieved during the robotic arc welding process.

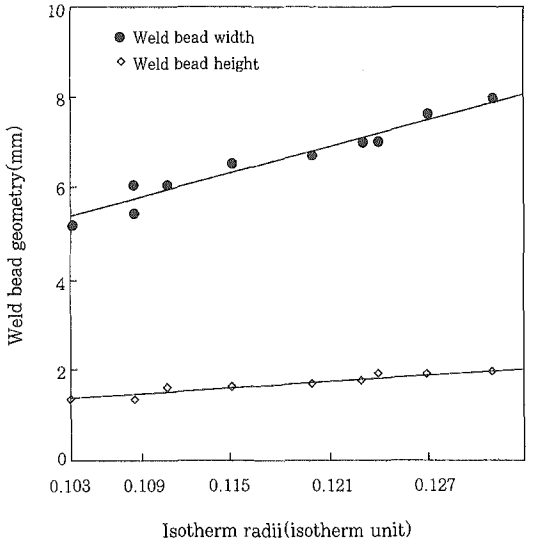


Fig. 8 Isotherm radii versus bead geometry for 5 mm mild steel.

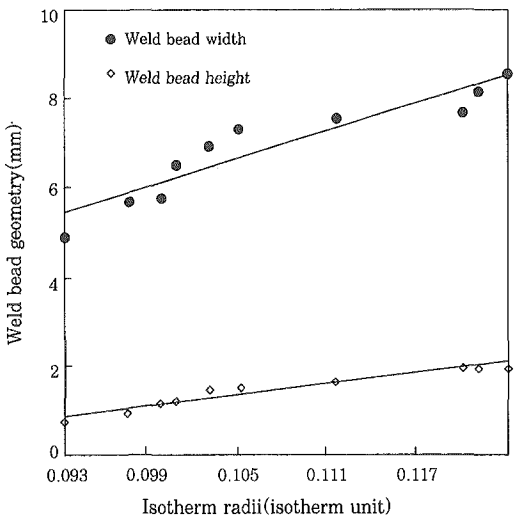
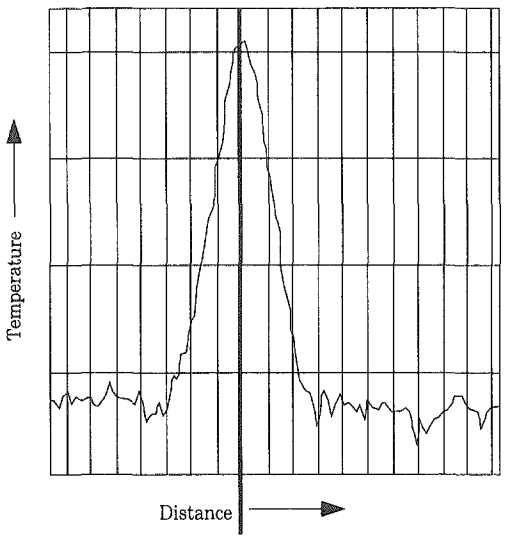
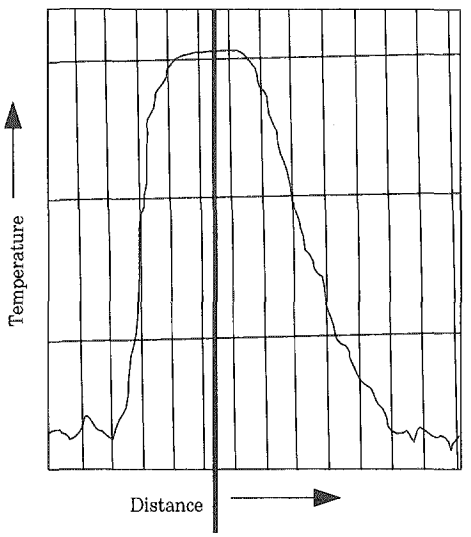


Fig. 9 Isotherm radii versus bead geometry for 10 mm mild steel.

Further experiments on close fit butt welds using the same process parameters was designed to acquire both on-seam and off-seam temperature distributions in one data acquisition run. The designed weld path starts with a torch offset of 1.2cm to the left of the seam and crosses the seam to end with the seam. The experimental result was analysed to obtain a quantitative relationship between the torch offset and asymmetry of the isotherms and to identify the asymmetry, thermal profiles of on-seam and off-seam weld conditions. Fig. 10 shows two isotherm patterns depicting the effect of torch offset on the thermal distribution of the plate. In on-seam welding conditions, the torch is aligned with the center of the seam so that thermal distribution yields isotherms which are symmetric about the center of the torch as shown Fig. 10(a). However in off-seam welding conditions, the arc is offset from the seam so that the heat imput is unequally distributed on either side of the joint as shown Fig. 10(b). The unequal heat distribution caused by the contact resistance of the seam is manifested in the asymmetry of the thermal profiles. The experimental results indicated that seam tracking may be based on the difference in radii of isothermal curves to the left and right of the seam. Although the potential of the technique for adaptive control during robotic arc welding has been proved, future research and development work is needed to assess its viability.



(a) Arc position - on seam



(b) Arc position - off seam

Fig. 10 Temperature versus distance profiles

4. CONCLUSIONS

The infrared thermography and the machine vision sensing have shown to control the bead width and bead height during the arc welding of AS 1204 mild steel plates. It was also found that the width of the thermal line scan was directly proportional to the bead width and bead height. Adaptive control using infrared thermography may eventually be achieved with

the development of appropriate computer interface with both the weld control and the technique employed in infrared thermography.

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