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A dynamic welding heat source model in pulsed current gas tungsten arc welding

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ABSTRACT

A time-dependent welding heat source model, which is defined as the dynamic model, was established according to the characteristic of PCGTAW. The parabolic model was proposed to describe the heat flux distribution at the background times. The recommended Gaussian model was used at the peak times due to the bell-shaped temperature contour. The dynamic welding heat source was composed of these two models with a function of time.

To assess the validity of the dynamic model, an experiment was conducted in which the pulsed current gas tungsten arc deposits on the plate. From the comparison of the experimental and the simulated values, it can be concluded that the dynamic heat source model, which uses the parabolic model at the background time, is more realistic and accurate under the same welding conditions.

1. Introduction

With the development of the computer and numerical analysis technologies, the FEM has become a powerful and reliable technique for prediction in the welding processing industry. The temperature field contains sufficient information about the quality and properties of the welded joint, and determines the distortion, residual stresses, and reduced strength of a structure in and near the welded joint. The temperature field is also the foundation of the metallurgical analysis and phase change analysis. To obtain an accurate welding temperature field, Goldak et al. (1984) reported that the importance of a good welding heat source model has been emphasized by many investigators.

Many welding heat source models have been developed up to now, and the Gaussian model and the double ellipsoidal model are the most popular models among them. Some good welding heat source models can accurately predict the temperature field. However, most of these models were developed on the assumption that the heat sources are static and not varied with time in the welding processes. These models are no longer realistic for some dynamic welding processes, such as the pulsed current gas tungsten arc welding (PCGTAW). The objective of this paper is to develop a more realistic and accurate welding heat source model for PCGTAW.

PCGTAW was developed in 1950s and is widely used in the manufacturing industry today. In PCGTAW, the welding current is varied periodically from the peak current to the background current. Balasubramanian et al. (2008) indicated that the heat energy to melt the base metal is provided mainly by the peak current, while the background current is set at a low level to maintain a stable arc. Therefore, the background time can be seen as brief intervals during heating, which allow the heat to conduct and diffuse in the base metal.

PCGTAW is a widely utilized welding process. Traidia et al. (2010) and Balasubramanian et al. (2008) pointed out that PCGTAW has the following advantages over the constant current gas tungsten arc welding (CCGTAW): (a) lower heat input; (b) narrower heat affected zone; (c) finer grain size; (d) less residual stresses and distortion; (e) improved mechanical properties; and (f) enhanced arc stability to avoid weld cracks and reduce porosity, etc.

However, the welding parameters of PCGTAW are more complex to define than CCGTAW, and the choice of parameters with PCGTAW remains empirical. The parameters of PCGTAW were depicted by Madadi et al. (2012) in Fig. 1. A great deal of work has been conducted on the numerical simulation of PCGTAW. Fan et al. (1997) developed a two-dimensional model using the boundary fitted coordinate system to simulate the PCGTAW process. Kim and Na (1998) computed the fluid flow and heat transfer in partially penetrated weld pool under PCGTAW by the finite difference method. Traidia and Roger (2011) used the unified time-dependent model to describe the fluid flow, heat transfer and electromagnetic fields in the three regions respectively. Many investigations have been conducted, but far less work has been done on the development of the welding heat source model under PCGTAW.

Several heat source models have been developed. They are classified in Table 1. Most of the current heat source models have been

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Table 1
The classification of current welding heat source models.

	One-dimension	Two-dimension	Three-dimension
Uniform distribution mode	Point heat source	Plane heat source	Columnar heat source
	Line heat source	Circular mode	–
	–	Tripped heat source	–
	–	Square heat source	–
Gaussian mode	–	Circular mode	Circular disk heat source
	–	Oval-shaped heat source	Columnar heat source
	–	Double oval-shaped heat source	Cuboid heat source
	–	Tripped heat source	Rotary body heat source
	–	–	Conic heat source
	–	–	Hemispherical heat source
	–	–	Semi-ellipsoidal heat source
	–	–	Ellipsoidal heat source
	–	–	Double ellipsoidal heat source
Exponential decay mode	–	–	Exponential decay heat source

developed on the geometrical shape and distribution in space, but time as an important factor, which has rarely been considered, in the model design. In fact, the heat source is varied with time in some dynamic process, e.g. in the PCGTAW. Therefore, a time-dependent heat source model, which is available for the dynamic process, is necessary to be developed.

In this paper, a dynamic finite element model of welding heat source under PCGTAW is established. Then the moving, time-dependent heat source was attempted to load onto the structure, and the FEM was used to compute the temperature field through the software ANSYS.

2. Theoretical formulations

2.1. Model consideration

With the help of high speed CCD, Traidia and Roger (2011) used an infra-red camera to capture the characteristic of a welding arc under PCGTAW, and some good images were obtained which at the background and peak times (see Fig. 2).

It is easy to see that there is significant difference between the peak time and the background time, and the arc is bell-shaped during the peak duration, but not during the background duration.

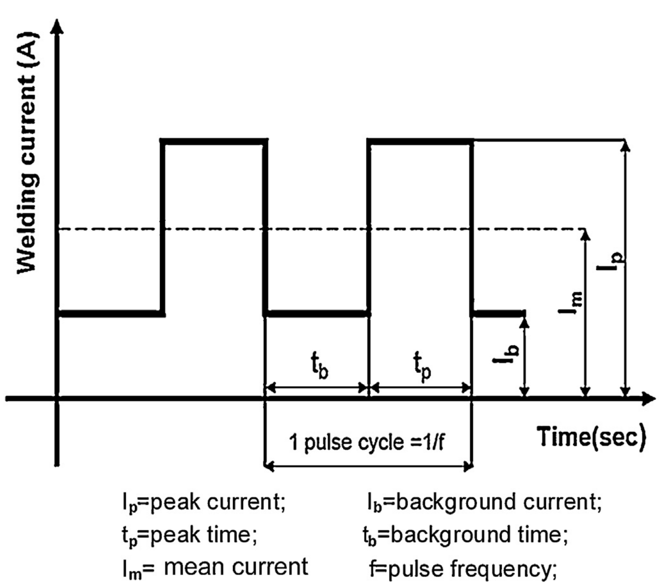

Fig. 1. Pulsed current GTAW process parameters (Madadi et al., 2012).

In contrast to constant current welding, the heat input in PCGTAW is supplied mainly during the peak times, and the heating is halted periodically during the background times. Xu et al. (2009) pointed out that the characteristic of discontinuity during heating under PCGTAW is more obvious when the frequency is low. So, two heat source models must be proposed which will be available in the peak times and background times. Considering the bell-shaped temperature contour, the recommended Gaussian model was used during the peak times; the big problem at present is to propose a good heat source model which is available during the background times.

Some good experience can be obtained from the proposed process of the Gaussian heat source model. The design of the experiment was made to investigate the heat and current distribution of GTAW, which consists of splitting a water cooled copper anode. Measure the heat flux to one of the sections as a function of the arc position relative to the splitting plane. The radial heat distribution can then be derived by an Abel transformation of the measured heat flux on the anode. The distribution of heat on the anode is a result of a series of collisions of electrons with ionized atoms as electrons travel from the cathode to the anode. The energy released on the anode surface carried by the electrons constitutes most of the heat, and Tsai and Eagar (1985) considered that the distribution of the heat flux on the water cooled anodes should closely approximate to the distribution across the weld pool.

Similarly, regarding the PCGTAW in this paper, it can be also considered that the anodic heat flux distribution is closely approximate to the heat distribution across the weld pool.

2.2. Mathematical model

Traidia and Roger (2011) obtained the numerical simulation result of the radial heat flux distribution at the anode between the pulsed current – background time and peak time – and the mean current, which are shown in Fig. 3a. The third curve which the arrow points to is the radial heat flux distribution during the background time.

To simplify the problem, it can be assumed that the radial heat flux at the background time is parabolic shape, which passes through three points $(0, q(0))$, $(R_b, 0)$, $(-R_b, 0)$ in the coordinate ξ–x plane. The function of radial heat flux distribution at the background time can be written as:

$$q(x, \xi) = q(0)\left(1 - \frac{x^2}{R_b^2}\right), \quad -R_b \le x \le R_b \tag{1}$$

where $q(0)$ is the maximum value of heat flux and R_b is the radius of the power density.