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# A comparative study on the performance of artificial neural networks and regression models in modeling the heat source model parameters in GTA welding

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ABSTRACT

Welding is one the most important joining methods Analytical and FEM techniques are commonly employed to model various welding processes. The heat source model is a key part of welding simulation. Proper determination of heat source parameters is one of the main factors in the accuracy of the welding simulation. In this study, artificial neural networks and regression modeling have been employed to establish the relationships between welding input variables and the parameters for the Goldak heat source model. The 27 data needed for modeling has been gathered based on full factorial design. While ANN slightly outperforms regression, both ANN and second order regression functions have good agreements with actual experiments. The approach presented here may be used to accurately specify heat source parameters for any given set of welding process variables.

## 1. Introduction

Various types of welding operations are well-known as the permanent joining methods. But, such techniques have some difficulties to apply including the need of skilful operators, time consuming and expensive operations. These are the reasons that the welding simulations are attended more and more. Analytical and numerical simulations are the two fields that can be replaced by welding experiments to avoid the welding difficulties. Constructing a model which describes the properties of the real welding operation accurately and precisely depends on several factors. For instance, the finite element (FE) modeling of such processes is highly affected by the simplifying assumptions, selecting the type of elements, method of heat source modeling, and etc. Among all, the heat source provides the thermal energy of welding. The temperature histories of any point of the weldment produced by the heat source have a fundamental role on the mechanical properties of the welded workpiece. One of the challenges in finite element modeling of the welded structures is to define a heat source model which is accurately able to simulate the heat input to the weldment. Usually, the parameters of a selected heat source model are estimated by using the weld bead geometry which is determined by some experiments. This procedure can undo the simplicity of the simulation. Therefore, proposing some methods to estimate the parameters of the heat source model is vital in welding simulation in terms of the hard experimental works.

Rosenthal [1] presented a moving heat source based on the Fourier theory of heat flow. But the Rosenthal model had some essential drawbacks for temperatures in or near the fusion zone (FZ) and heat affected zone (HAZ). The errors of the Rosenthal model has been discussed in detail by Myers et al. [2]. Goldak et al. [3] proposed a double ellipsoidal model for weld heat sources to simulate both the shallow and the deeper penetration arc welding processes. Furthermore, it has the possibility to apply the model for non-axisymmetric welds such as strip electrodes or dissimilar metal joining. This model has been widely applied in various studies.

A method was developed to estimate heat source parameters in welding simulation by Jia et al. [4]. They have performed a sensitivity analysis of heat source to reduce the complexity of the model. The relationships between heat source parameters and weld pool characteristics (fusion width (W), penetration depth (D) and peak temperature (Tp)) obtained with both the multiple regression analysis (MRA) and the partial least-squares regression analysis (PLSRA).

Sharma et al. [5] estimated the double ellipsoidal heat source model parameters for twin-wire application. The parameters were estimated for a different set of welding conditions.

A combined heat source model was proposed for the numerical analysis of temperature fields in keyhole PAW process by Wu et al. [6]. Belitzki et al. [7] proposed a method to simplify the finite element simulation of the welding processes. In this research, the image processing method was used to determine the weld seam contour, and the heat

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source parameters were calibrated using the optimization procedure. Yadaiah et al. [8] have optimized this parameter for better finite element modeling of the welding process. Then, they calculated the weld dimensions by a 3-D finite element simulation of linear GTAW process. It has been shown that the FE results were in agreement with the experiments. Using both numerical and analytical approaches, Bag et al. [9] determined the heat source model. Using the proposed method, there is no need to prior information about the final joint dimensions as a difficulty.

The brief survey of related literature showed that the heat source model is a key factor for finite element simulation of various fusion welding processes. This study aims to determine the heat source parameters based on the model first proposed by Goldak et al. [3]. For this purpose, artificial neural networks (ANN) and regression models were implemented. The main welding parameters affecting the heat source model dimensions have been considered as the input variables of the ANN and regression models. The results of both methods will be compared, and the concluding remarks will be highlighted.

## 2. Goldak heat source model

One of the main concerns in numerical simulation of welding is the heat source modeling. There are various methods to overcome this challenge, but most of them have some drawbacks. For example, the Rosenthal model [1] had some essential disadvantages for temperatures in or near the fusion zone (FZ) and heat affected zone (HAZ). The infinite temperature assumed in the source and the temperature dependency of the material thermal properties increases the error while the heat source is approached [10]. Pavelic et al. [11] proposed that the heat source should be distributed. They suggested a Gaussian distribution of flux which is deposited on the surface of the weldment. Although Pavelic's model is certainly an important improvement, some other authors have recommended that the heat should be distributed all over the molten zone to simulate more accurately the digging behavior of the arc. Paley [12] and Westby [13] considered a constant power density distribution in the FZ using a finite difference model, but there was no criterion to estimate the length of the molten pool in their research. Furthermore, it is not easy to accommodate the complicated geometry of the real weld pools with the finite difference approach.

As stated before, Goldak et al. [3] proposed a double ellipsoidal heat source model based on the Gaussian distribution. The proposed model was non-axisymmetric and three-dimensional. It was more realistic and more flexible model compared to the other models suggested for the weld heat sources. Using this model, both shallow and deep penetration welds can be adapted in addition to asymmetrical states. The proposed model has been shown in Fig. 1

According to this model, the power density due to the heat source is divided into two semi-ellipsoid parts: front part and rear part. The front part of the heat source is demonstrated via Eq. (1).

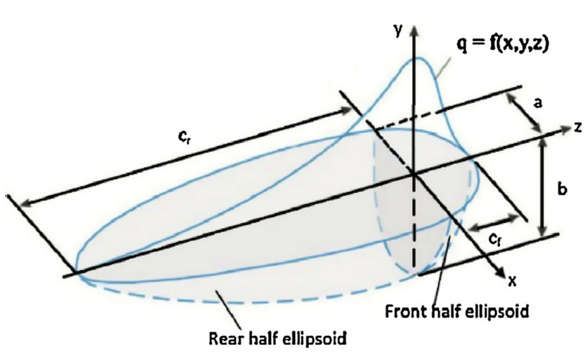


**Fig. 1.** Goldak's heat source model [4].

$$q_f = \frac{6\sqrt{3} f_f Q}{abc_f \pi \sqrt{\pi}} e^{-(3x^2/a^2+3y^2/b^2+3z^2/c_f^2)} \tag{1}$$

And for the rear part Eq. (2) is used.

$$q_r = \frac{6\sqrt{3} f_r Q}{abc_r \pi \sqrt{\pi}} e^{-(3x^2/a^2+3y^2/b^2+3z^2/c_r^2)} \tag{2}$$

Where, x, y, and z are the local coordinate system of the model. The parameters a and b are the semi-axes of the ellipsoids. Furthermore, $c_f$ and $c_r$ address the segments of axes in front and rear ellipsoids respectively. The fractions of deposited heat in front and rear of the ellipsoids are $f_f$ and $f_r$ respectively. These fractions are computed by Eqs. (3) and (4) [14].

$$f_f = \frac{2c_f}{c_f + c_r} \tag{3}$$

$$f_r = \frac{2c_r}{c_f + c_r} \tag{4}$$

Using Eqs. (3) and (4), it can be deduced that $f_f + f_r = 2$.

In Eqs. (1) and (2), Q is computed via Eq. (5).

$$Q = \eta IV \tag{5}$$

Where, $\eta$ is the arc efficiency, I is the welding current, and V addresses the welding voltage.

In the following sections, two methods have been implemented to determine the values of heat source parameters i.e. a, b, $c_f$, and $c_r$ which reduces the need for excessive experiments.

### 2.1. The challenges of the heat source models

One of the key parts in any heat source model is the way that the values of its parameters are specified. A main drawback in heat source modeling is that, in terms of their parameters values; they are valid only for limited ranges of welding parameters. This causes them to work accurately only under certain conditions. Traditionally, the values of heat source model parameters are determined using weld bead geometry obtained from a number of welding tests. In turn, the heat source model may be valid only for the welding parameters used in the tests performed. If the welding input parameters are significantly varied, then the parameters of the heat source model should be modified accordingly. This usually requires several welding tests using the new welding settings.

To overcome these problems, in this study, two methods have been implemented to estimate the values of Goldaks' parameters; i.e. a, b, $c_f$, and $c_r$. The advantages of the presented techniques compared to the other analytical or numerical methods are: using pure experimental data in modeling procedure, eliminating the need of considering various simplifying assumptions, eliminating the need of expensive, time consuming, and hard experiments, and reducing the computational time compared to the analytical or numerical approaches.

In this study, according to the Goldak's heat source model, four characteristics of the weld pool geometry including front and rear length of semi-ellipsoids ($L_f$ and $L_r$ respectively), weld width (W), and weld penetration depth ($D_p$) were measured. The first three aforementioned parameters were measured with 20 times magnification and the weld penetration depth was measured with 50 times magnification. The OLYMPUS SZX9 optical microscope and the image processing software, the ImageJ, were implemented as the measuring tools.

The relationships between the selected weld pool geometries and the parameters of Goldak's heat source model have been presented via the following equations:

$$a = W/2 \tag{6}$$

$$b = D_p \tag{7}$$

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