Applied Mathematical Modelling 000 (2016) 1–14

Contents lists available at ScienceDirect

Applied Mathematical Modelling

journal homepage: www.elsevier.com/locate/apm

Multi response simulation and optimization of gas tungsten arc welding

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A R T I C L E I N F O

Article history:
Received 5 November 2015
Revised 15 September 2016
Accepted 10 October 2016
Available online xxx

Keywords:
Best TIG welding setting
GTAW welding
Definitive screening design
Welding optimization
Central composite design
Multi criteria optimization

A B S T R A C T

In the fabrication of a pressure vessel, the successful bending operation (after welding) demands higher tensile strength of weld bead. Therefore, to achieve typical tensile strength and hardness is the primary objective of this paper. Stainless steel 304 is widely used material in almost all the industrial applications, hence it is selected as a candidate material for study of tungsten inert gas (TIG) welding process. In order to produce, a high quality and reliable welding, the welding process needs to be *robust* in performance. A recently developed popular experimental approach known as definitive screening design (DSD) is used for process improvement. These optimum variable settings necessary for consistent welding are obtained through the application of simulation by using central composite design. The typical values of tensile strength and hardness are obtained at a *low value* of purging gas flow rate, filler rod dia.; *intermediate values* of root gap, plate thickness; and at *high values* of electrode dia., current, and gas flow rate.

1. Introduction

Tungsten inert gas (TIG) welding, is also known as gas tungsten arc welding (GTAW) or Heliarc welding. The latter name is due to Russell Meredith, who perfected this process in 1941 [1]. TIG welding utilizes non-consumable tungsten electrode for producing high quality weld in which, arc is shielded by inert gas such as Ar or He or N_2, or their combinations. Mechanical properties of weld are considered as a function of input and process variables.

In TIG welding of Al-Mg alloy (thickness 2.14 mm), A. Kumar and S. Sundarrajan [2] used four process parameters: peak welding current, base welding current, pulse frequency, and travel speed. These four variables were used at two levels by applying Taguchi L8 (2^7) design. Significant factors are identified by using ANOVA, whereas mathematical relation modeled using regression analysis. M. Yousefieh et al. [3] used super duplex stainless steel (SDSS) of thickness 7 mm with process variables such as, pulse welding current, background welding current, pulse frequency, and % on time. According to their observation, % on time is the most influencing factor. H. Lin [4] used Inconel 718 alloy of 6.35 mm thickness for optimizing activated TIG welding process. Taguchi design of L18 orthogonal array (OA) is implemented for improving quality characteristics by minimizing the causes of variation. Arc length, travel speed, welding current, gas flow rate, angle of electrode tip, and mixed flux type are considered as the process variables. Gray relational analysis (GRA) is used to convert multiple responses into single response by assigning gray relational grade (GRG) to individual responses. R. Adalarasan and M. Santhanakumar [5] studied the response variables such as yield strength, ultimate tensile strength, and microhardness of AA

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http://dx.doi.org/10.1016/j.apm.2016.10.033

For single butt weld, $\sigma_t = P/(t \times l)$, *where* σ_t *= allowable tensile strength,* l *= weld length*
P *= transverse load applied,* t *= weld throat,*

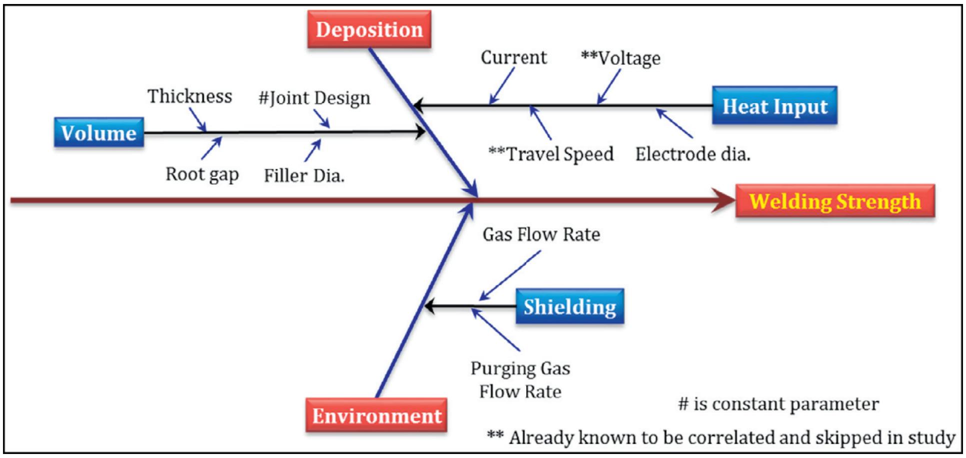

Fig. 1. Ishikawa diagram for manual TIG welding.

6061 with TIG and metal inert gas (MIG) welding. These multiple responses are handled by using integration of desirability function and GRA. In their study, welding current is found to be a major contributing variable. Moreover, it is proved that the results of TIG welding are better than MIG welding. G. Magudeeswaran et al. [6] used Taguchi design with L9 (3^4) OA for optimizing TIG process parameters on duplex stainless steel (DSS) of 6 mm thickness. Electrode gap, travel speed, welding current and voltage are considered as process variables. These authors found that the optimum condition corresponds to an aspect ratio of 1.24. A. K. Srirangan and S. Paulraj [7] used three welding variables current, welding speed, and voltage. Two responses yield strength and ultimate tensile strength are optimized using GRA. However, the input variables are correlated, so it cannot be guessed, whether the true optimum is achieved. Since, input variables are correlated, it is highly possible that the interaction has greater impact on the response. Definitive screening design is the most promising experimental design approach invented by B. Jones and C. Nachtsheim in 2011 [8]. This design reveals main effect, quadratic and interaction effect in minimum number of runs by using three levels of variables.

Through above review, it is observed that the different variables in TIG welding affects the weld properties in different manner. Ishikawa diagram for manual TIG welding process, which is regarded as a system representing the welding process is shown in Fig. 1 and various factors affecting the process are enlisted. The root gap, if kept at too low level weakens the weld, whereas too high a level allows the weld to pass without any bondage. Thus, root gap plays an important role in the formation of weld, thereby it affects the mechanical properties and hence it is considered as a one of the variable. Since the weld strength is a function of throat thickness which depends upon the plate thickness [9].

Generally, the filler rod diameter is selected based on the parent metal composition and the thickness to be welded [10]. Therefore, filler rod diameter and plate thickness are estimated to be probable input variables [9,11,12]. If the gas flow rate during welding operation is continuous and uniform then it provides a better shielding to the weld pool and thus strengthens it. While the oxidizing gases formed on the opposite side of the weld can introduce porosity in the weld [4,10,11], which results into decrease in the weld strength. Therefore, to remove these oxidizing gases, a uniform flow of purging gas is required [10,13,14]. Thus, gas flow rate and purging gas flow rate are also considered as probable variables. The current is correlated with travel speed [15] and voltage, hence, only current is taken as input variable. Moreover, travel speed is a function of thickness [16], thus thickness is independent variable, hence, considered as system variable for process study. Electrode diameter is generally chosen of higher size for longer life, but it requires high current for starting arc [16]. The final list of input and process variables for study are shown in Fig. 2.

This paper attempts to use DSD for screening and central composite design (CCD) for optimization, and desirability function for simultaneous optimization of multi response variables. This strategy is not used previously and hence it is implemented in this paper. Moreover, simultaneous study of effect of seven variables on response variables is novelty of this paper. From robustness viewpoint, the properties of weld should be consistent that will yield typical tensile strength and typical hardness. The problem formulated in this paper is: *To find the optimum values of input and process variables in TIG welding, which will yield the typical tensile strength and the typical hardness*. Tensile strength (primary objective) and hardness (secondary objective) are correlated properties [17]. This implies that when tensile strength is achieved the hardness should not increase sporadically resulting into brittleness of weld bead.

Please cite this article as: M.V. Patil, Multi response simulation and optimization of gas tungsten arc welding, Applied Mathematical Modelling (2016), http://dx.doi.org/10.1016/j.apm.2016.10.033