STUDY OF THE WELD POOL SHAPE VARIATIONS WITH THE WELDING PARAMETERS FOR OPTIMIZATION UNDER TIG WELDING PROCESS

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Liha Lateng
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LIST OF ABBREVIATIONS

ANOVA	Acronym for analysis of variance, a statistical data treatment for sorting out the relative influence of factors to variation of results.
DOE	Acronym for design of experiments.
Error	Amount of variations in the response caused by factor other than controllable factors include in the experiment.
Factors	Input variables or parameters to the project.
Levels	Values or condition of the factors utilized in carrying out an experiment.
OA	Orthogonal array. Set of tables containing information to determine least number of experiment.
S/N ratio	The ratio of the power of the signal to the power of noise (error). A high S/N ratio will mean that there is high sensitivity with the least error of measurement. A higher value of S/N is always desirable regardless of the quality characteristics.
SS	Stainless steel
TIG	Tungsten inert gas

Kajian variasi bentuk kolam kimpalan dengan parameter kimpalan untuk pengoptimuman ke atas kimpalan TIG

ABSTRAK

Kajian ini dijalankan untuk mengkaji tindak balas-pelbagai proses kimpalan tungsten gas lengai (TIG) untuk mendapatkan suatu parameter optimum berdasarkan bentuk kolam kimplan menggunakan kaedah Taguchi dan analisa hubungan Grey. Empat eksperimen dijalankan berdasarkan $L_4(2^3)$ orthogonal array yang didapati melaui kaedah Taguchi, di mana faktor yang ingin di optimumkan ialah arus elektrik kimpalan (amp), kadar aliran gas (l/min), dan unjuran tungsten (mm), setiap parameter telah disetkan kepada suatu tahap untuk mendapatkan suatu fungsi objektif. Fungsi objektif seperti tinggi manik dan lebar manik kimpalan daripada bentuk kolam kimpalan atau manik kimpalan geometri telah di pilih untuk di analisa menggunakan bahan austenitic keluli tahan karat 302. Pendekatan Taguchi diikuti dengan analisa hubungan Grey di gunakan untuk menyelesaikan masalah tindak balas-pelbagai ini hasil daripada pendekatan ini menunjukkan parameter bagi kimpalan TIG dapat di optimumkan pada level 2 arus kimpalan elektrik (185 amp), level 2 kadar aliran gas (10 l/min) dan level 1 unjuran tungsten (3 mm). ANOVA atau analisis varians turut di jalankan untuk mengetahui faktor manakah yang memberi impak signifikan kepada proses kimpalan tungsten gas lengai. Berdasarkan ANOVA faktor yang mempunyai pengaruh yang signifikan terhadap proses kimpalan TIG adalah arus kimpalan elektrik sebanyak 0.948341, di ikuti dengan unjuran tungsten (0.039414) dan kadar aliran gas (0.012245). Faktor optimum telah disahkan melalui eksperimen tambahan untuk pengesahan. Eksperimen pengesahan menunjukkan analisa hubungan Grey bertambah baik sebanyak 0.338903.

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ABSTRACT

This study investigated the multi-response optimization of tungsten inert gas welding (TIG) process for an optimal parametric combination to yield favourable weld pool shape of welded joints using the Taguchi and Grey relational analysis method. Four experimental runs based on $L_4(2^3)$ orthogonal array of Taguchi method were performed to derive the desire objective function to be optimised within experimental domain correspond to the number of parameters and their levels which is welding current (amp), gas flow rate (l/min), and tungsten stickout (mm). The objectives function have been selected in relation to parameters of TIG welding weld pool shape or weld bead geometry i.e. weld bead height and weld bead width of material austenitic 302 stainless steel with 3 mm thickness. The Taguchi approached followed by Grey relational analysis used to solve the multi-response optimization problem. Result based on this method shows that the optimised process combination parameter for TIG welding process are welding current at level 2 (185 amp), gas flow rate at level 1 (10 l/min), and tungsten stickout at level 1 (3 mm). The significance of the factors on overall quality characteristics of the weldment has also been evaluated quantitatively by the analysis of variance (ANOVA). Based on the ANOVA it shows that welding current is the most significant factor with 0.948341, followed by tungsten stickout (0.039414) and gas flow rate (0.012245). Optimal result have been verified through additional experiments. The conformation test indicates the grey relational grade is improved to the significant value of 0.338903.

CHAPTER 1

INTRODUCTION

1.0 Overview

Welding is one of the methods used for joining materials in the most efficient and economical way (Cary & Helzer, 2005). The recent growing behind welding enormously invented opportunities for more value added to welded structures and products. The conventional examples are automobiles, air-crafts, ships, trains, space shuttles, offshore platforms, to name but a few. As this structures are dominated by metals, the search for the use of metals in manufacturing innovative products by utilizing welding as the main joining process is highly indispensable (Gyasi, 2013).

Tungsten inert gas welding (TIG) is an important welding process for hard-to-weld metals such as stainless steel. This arc welding use non-consumable tungsten electrode incorporated with inert gas as arc shielding (Cary, 1989). The strong characteristic of TIG weld can be defined by the weld pool shape (weld bead geometry) due to its vital role in determining mechanical properties of the weld (Zhang, Kovacevic, & Li, 1996). The application of statistical experimental design, linear regression modelling, and neural network has been applied to study the effect of certain parameters on the bead of weld. It has been validate the parameters of welding process are strongly correspond to the bead geometry, and it is crucial to select the parameters to get the best optimum weld pool shape (Zeng, Lucas, & Fang, 1993). Study conducted by Tarng and Yang (1998) stated handbook and experience can be used as a guidelines to ascertain desired welding parameters. Nonetheless, it does not ensure that selected welding parameters can result in the optimal or nearest to optimal weld bead geometry as the particular welding machine and environment might affected the welding process.

Combination of welding parameter has direct and indirect influence onto the bead geometry as the process interact in complex manner thus affect the mechanical properties altogether. Study by Esme et al. (2009) reveal that weld pool character can be categories in several variables bead geometry which is heat affected zone, bead width, bead height, penetration and area of penetration. Wherein this variable was impacted from certain setting parameter combination i.e. welding speed, welding current, shielding gas flow rate and gap distance. This variables also indeed significant in determining the mechanical properties of the weldment such as tensile load. In recent year, there are many studies conducted using the Taguchi method to solve the optimization process of production. For example, Juang and Tarng (2002) in their study of process parameter selection for optimizing the weld pool geometry in the TIG welding of stainless steel state that weld pool has several quality characteristics, for instance, the front height, front width, back height and back width of weld pool. In consideration of this quality characteristics and also the selection of input welding process parameter, the Taguchi method is opted for analyse and effects of the input welding process parameter on the weld pool geometry evaluated. Thus ascertain and deduce the input parameter of welding process that give the optimal weld bead geometry. The application of Taguchi method incorporated a well-balanced experimental design consisting of a limited number of experimental runs called the orthogonal array (OA) and signal-to-noise ratio (S/N) which serve the objective function to be minimized within experimental limits. Meanwhile, analysis of variance (ANOVA) is used to determine the most significant factor affect the experiment (Sharma & Khan, 2014).

Besides the application of Taguchi, another popular method used in the optimization process is the Grey relational analysis. Grey relational analysis (GRA) method was employed in the analysis of the experimental result. This grey system pioneer by Professor Deng Julong (1982) in his paper entitled "The control problem of grey system". Grey system is a new method for studying uncertain problem with less data and poor information. It is being used in study with small sample, poor information, and system with partially know information (Liu & Forrest, 2007). Study conduct by Rai and Dewan (2014) stated that grey method analyse a variety of process which possess multiple performance characteristics. In actual situation, a situation can be differentiate in two state of perfectly black i.e. with no information nor perfectly white i.e. with complete information, both situation described as being grey. Basically, GRA is used to resolve problems which have interrelationship between designated performance characteristics. Using GRA method become quite successful when applied in the studies, this can be seen through several research by Esme et al. (2009); Chandresh and Sandip (2013); Iska et al. (2013); Yang (2011); P. A. Kumar, Kumar and Chandra (2014); Datta and Mahapatra (2010); Rai and Dewan (2014); J. L Lin and C. L Lin (2002); Al-Refaie, Al-Durgham, and Bata (2010), and to name a few.

For GRA to be used, data based on the multi response characteristics were first being normalize in the range of zero and one. This process known as grey relational generation. After then, the grey relational coefficient is calculated based on this normalize data to express the relationship between the desired and actual experimental data. Thereafter, overall grey relational grade is calculated by averaging the grey coefficient correspond to each selected process response. Typically, the GRA method converting a multi response process optimization problem with the objective function of overall grey relational grade. The corresponding level of parametric combination with the highest grey relational grade would be considered as the optimum process parameter (P. A. Kumar, Kumar, & Chandra, 2014).

For this study, Taguchi method is used to determine the number of welding process is reported. This tool introduced by Taguchi (1986) for design of high-quality systems imparting a simple, efficient, and systematic approach to optimise design for performance, quality, and cost. Taguchi method is advantages for the discrete and qualitative process parameters, the parameter design incorporated with Taguchi method can produce the optimise quality characteristics using the selected settings of process parameters and could reduce the error sensitivity of the system performance to the variation sources (Tarng & Yang, 1998). Besides this, details of experiment work on stainless steel by tungsten inert gas (TIG) to yield desired quality in terms of weld pool shape geometry as influenced by current (Amp), gas flow rate (1/min), and tungsten stickout (mm) are varied at two different level. The Taguchi approach together with application of Grey relational analysis method is carried out to solve this optimization problem.

This study consists of few chapter. Chapter 1 emphasised as a medium of introduction for the research study and briefly discuss the general overview for this study. This chapter highlighted several aspect such that background of study, problem statement, objectives, scopes of study, limitation, significance of the study, and division of thesis. The history and emerging development of welding process in the industries are also described in this chapter along with some review of previous study, while in chapter 2 researcher review some relevant literature pertaining to the material, process, and result of past study in related to TIG welding process and other related method in optimization. Meanwhile, Chapter 3 is the methodology for the study, flowchart is summarize from the overall study. Beside this detail from the experiment including machine equipment has been emphasize along with the Taguchi parameter design and application of Grey relational method. In Chapter 4, presentation of results, analysis and discussion from the experiment is presented. Last but not least, Chapter 5 provided the conclusion drawn from the study and recommendation for future study scope.

1.1 Background of study

Welding is a manufacturing process of metal-joining by using two or more pieces of materials together to form a permanent bonding using the specific welding process in the present of heat. This part of the material can be ranging from metal of ferrous or non-ferrous, ferrous metal is a material that contains an iron while non-ferrous metal is a material that do not have the iron contain within it. According to Larry Jeffus (2004) in the book of Welding Principles and Application, a weld is defined by the American Welding Society (AWS) as "localized coalescence of fusion or growing together the materials grain structure that being welded of metals or non-metals produced by heating the materials to the required temperatures, with or without the application of pressure, and with or without the use of fillers materials". Technically welding is a manufacturing process used sources of heat and accompany by certain parameter with the presence of filler or without the presence of filler metal to form bonds between two materials, filler material added only when to complete the welding of a joint.

When encountering with welding, surface finish and weld quality become crucial as in manufacturing world, quality is vital and can be defined as degree of satisfaction as provided by the procured product. In fields of welding, welding quality can be seen or depending on the mechanical properties correlated to the weld pool shape (Esme et al., 2009). One of the welding types that being used widely in the Manufacturing Industries or any other related industries such as aerospace is Tungsten Inert Gas or simply known by the acronym of the TIG welding process. The TIG is referred as Gas Tungsten Arc Welding (GTAW). However, in the late 30s to early 40s the GTAW process is called Heliarc as the early development of process helium gas is the primary shielding gas used to weld magnesium and this cause limited application of GTAW.

This arc welds produced through the electrical heat between non consumable tungsten electrode and work, producing molten onto the work forming a weld pool shape, work here refer to the part being welded. The conductive ionized inert gas produced this electrical arc also give protection to the electrode, the molten weld pool and prevent contamination of weld metal from the atmosphere. Typically TIG welding equipment comprises of torches, work clamp, shielding gas, regulator or flowmeter, power sources, gas valve and work cable.

The input of parameter welding have a significant role for determine the weld pool shape as well as the mechanical properties and can be considered as a multi-input and multi-output. However, in certain point a weld quality did not only depend through the parameter alone, but the surrounding area and the condition of the welding machine and equipment can give a significant effect on the quality of weld being produced (Benyounis & Olabi, 2008). Research conducted by Dongjie Li et al. (2012) stated that input parameters such as welding speed, current and arc length could affect the weld pool shape and exhibit different behaviours. From what has been reported this parameter formed weld shapes that is wide and shallow under parameter of speed from 1.5 mm/s to 5.0 mm/s with a constant welding current of 160A and arc length of 3mm. In the meantime the shape of weld pool caused by the parameter of arc length ranging from 1mm to 7mm under constant current of 160A and welding speeds of 2mm/s are wide and shallow. The effect of welding current on weld pool shape exhibit wide and shallow shapes, it is investigated from 100A to 240A at a constant welding speed of 2mm/s and arc length of 3mm. Therefore, from this research it concludes that different input parameter could affect the shape of the weld pool and changing those parameters also will directly change the weld quality.

During the welding process inert shielding gas will protect the weld area from contamination as like been reported by Kumar (2014) in optimization of weld bead width using TIG of stainless steel. The study also mention that filler metal is normally used though welds known as autogenous welds, does not require the filler metal. The heat for TIG welding produced through the interaction between electrical arc and non-consumable tungsten electrode that come in contact with part to be welded, by then, shielding gasses will perform as blanket during welding thus eliminate active properties in the surrounding air.

Logically, a thin fused layer might be sufficient for connecting parts to be joined. Supposedly, to avoid wasting of energy, edge burn-off, sagging of the weld and deep weld end craters of welds the fusion layer should also not be thicker than necessary. The weld bead width is directly proportional to arc current, welding voltage and electrode diameter and indirectly proportional to the welding speed. Welding joint is considered to be a good or has the high quality if weld bead width and height are in minimum sizes, the less the bead width and height the better the weld quality and the least the distortion of welded plates and residual stresses.

Iyenger (2004) stated, optimization technique leads to the finding of the best parameters and best ways for one person to make decision and derive a maximum benefit from the available resources. Meanwhile, Lorenz K. et al. (2009) mentioned that a considerable number of parameters are applied just to get a very optimal parameter due to the different interactions, and the outcome of the investigation could be hardly compare. It can be stated that, to get the best design parameter and optimize parameter there could be a trial and error process. This can lead to a hard investigation and hence lots of time and cost incurred.

To encounter this, Taguchi method apply to ascertain and overcome problem such time consuming and costing, besides less trial and error in performing the investigation. The application of Taguchi method has been apply successfully in many research study to get the best optimum setting of parameter (Dongjie Li et al., 2012; Esme, 2009). This method is simple, efficient and systematic for the optimization of manufacturing process with minimum number of experiments. Taguchi method concentrate on the effect of variation on the product or process quality characteristics which can be done by proper designing the parameter by utilizing an orthogonal array design allowing a limited number well balanced experimental running, and signal-to-noise ratio (S/N ratio), which serve as the objective function to be optimized (Nirmalendhu, Ramesh, & Asish, 2014).

1.2 Problem statement

TIG welding is an important tool for many applications in industries because of the high quality welds produce. It can weld metal in any configuration and can be done in almost all position metal thickness ranging from 1 to 6 mm. But, this type of welding were not economically competitive in heavy industries and typically used other types of arc welding, such that gas metal arc welding. The reason is, it is hard to get a better combination of TIG welding parameter that likely suit the types of metal. Materials such as stainless steel is known to be having a very excellent technical properties, especially in term of strength, hardness and toughness. This properties make it useful in industries that requires part or product to be more