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Welded joints integrity analysis and optimization for fiber laser welding of dissimilar materials

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ABSTRACT

Dissimilar materials welded joints provide many advantages in power, automotive, chemical, and spacecraft industries. The weld bead integrity which is determined by process parameters plays a significant role in the welding quality during the fiber laser welding (FLW) of dissimilar materials. In this paper, an optimization method by taking the integrity of the weld bead and weld area into consideration is proposed for FLW of dissimilar materials, the low carbon steel and stainless steel. The relationships between the weld bead integrity and process parameters are developed by the genetic algorithm optimized back propagation neural network (GA-BPNN). The particle swarm optimization (PSO) algorithm is taken for optimizing the predicted outputs from GA-BPNN for the objective. Through the optimization process, the desired weld bead with good integrity and minimum weld area are obtained and the corresponding microstructure and microhardness are excellent. The mechanical properties of the optimized joints are greatly improved compared with that of the un-optimized welded joints. Moreover, the effects of significant factors are analyzed based on the statistical approach and the laser power (LP) is identified as the most significant factor on the weld bead integrity and weld area. The results indicate that the proposed method is effective for improving the reliability and stability of welded joints in the practical production.

1. Introduction

The availability of welded joints between dissimilar materials is continuously growing in the different applications such as the power, automotive, chemical and spacecraft industries. The greater flexibility, cost incurred towards costly and scarce materials are the attractive properties which dissimilar joints can provide. Despite of the advantages, the welding of dissimilar materials is not the easy work as the similar materials welding. The new issues, carbon migration, differences in thermal expansion coefficients, difficulty in heat treatment and electrochemical property variations, are usually existed in the dissimilar materials welding [1]. Compared with the conventional welding methods [2], the laser welding has been more widely used in industrial application. These process characteristics like high power density, high penetration, high productivity and narrow affected zone are particularly beneficial for the welding of dissimilar materials [3,4]. The laser welding as a valid way for the dissimilar materials welding is demonstrated by many researchers. Because of dissimilar materials differences in the physical, mechanical and metallurgical properties [5,6], the welding defects are often associated with welded joints. The lack of fusion, underfill, undercut and other related weld imperfections decrease the weld bead integrity directly. During the fiber laser welding (FLW) of dissimilar materials, the welding process parameters, such as the laser power (LP), welding speed (WS), focal position (FP), gap (GAP) and shielding gas (SG), greatly affect the integrity of weld bead. Therefore, adopting the proper process parameters is essential for improving the joints integrity and welding quality of dissimilar materials.

To ensure the high quality welding, the weld bead shape affected by the process conditions is studied by some researchers. Since the complicated relationships between welding process parameters and bead geometry, the welding parameters are often determined by the welder's experience, charts and handbooks in the practical production [7]. While they are not efficient for the continuously updated welding process due to the required time consuming inspection and trial. To obtain the desired weld bead

Abbreviations: FLW, Fiber laser welding; LP, laser power; WS, welding speed; FP, focal position; GAP, gap; SG, shielding gas; DOE, design of experiments; ANN, artificial neural networks; PSO, particle swarm optimization; BPNN, back propagation neural network; GA, genetic algorithm; S/N, signal to noise; ANOVA, analysis of variance; WF, the front-side width; WB, back-side width; BH, bead height; BM, base materials; WZ, weld zone; HAZ, heat affected zone

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and improve the welding quality, design of experiments (DOE) and statistical techniques are widely used in the welding through developing the relationship models between input variables and output responses. Tarng et al. [8] obtained the set of optimal welding process parameters using Taguchi method. Kumar et al. [9] employed Taguchi method and regression model to optimize the magnetic arc oscillation welding process parameters of AA 5456 aluminum alloy welds to improve the mechanical properties. The influences of welding current, welding speed, amplitude and frequency on mechanical properties were studied. Shojaeefard et al. [10] optimized the rotational speed, tool tilt angle and traverse speed in friction stir welding adopting Taguchi L_9. The tensile strength of welded joints was set as the optimal objective. As the developing mathematical models are time consuming and cumbersome in expressing the non-linear characteristics between the inputs and outputs, the artificial intelligence method is as an effective tool and introduced into the welding field. Katherasan et al. [11] proposed flux cored arc welding parameters optimization by artificial neural networks (ANN) and particle swarm optimization (PSO) algorithm. During the optimization process, the neural network illustrated good predicting capacity and the expected penetration, width and reinforcement of the weld bead were achieved. Dutta et al. [12] modeled TIG welding process using conventional regression analysis and neural network-based approaches. The results indicated that the genetic-neural approach could yield more adaptive predictions compared to that of the conventional regression analysis method. Yang et al. [13] reported the response surface methodology and back propagation neural network (BPNN) for the process parameters optimization in the lap welding. It showed that the average error from BPNN is less than that from regression models derived from the response surface methodology. Sathiya et al. [14] used ANN and genetic algorithm (GA) to optimize weld bead geometry and mechanical property in the laser welding. The optimal results were in good agreement with the actual values from the experiments. It is observed from the above studies that the artificial intelligence method is capable of identifying the optimal process with reasonable high accuracy in the welding of similar materials. However, the weld bead integrity is not considered in the optimization process.

Only a few investigations of welded joints integrity optimization in the dissimilar laser welding have been reported in the literatures. Ruggiero et al. [15] studied the weld-bead profile optimization of low carbon steel and austenitic steel in the laser welding. However, the weld integrity is not as the optimal objective and optimized in their research. Torkamany et al. [16] investigated the optimization of laser welding parameters for a sound weld with full penetration along the dissimilar interface. They could only achieve minimizing both the middle width and area of the weld bead. Furthermore, Sun et al. [17] reported the butt welding of Al/steel by using a 10 kW fiber laser welding system. This study only indicated that the good weld appearance was obtained at the appropriate welding parameters from several specimens analysis. Their work was focused on the feasibility of butt joining of aluminum and steel using laser filler wire.

This paper proposes an optimization method for improving weld bead integrity in the FLW of dissimilar materials using the artificial intelligence and statistical technique. The integrity of weld bead and the process parameters effects are analyzed. The relationship between the weld bead integrity and process parameters is established by the genetic algorithm optimized back propagation neural network (GA-BPNN). The predicted results from GA-BPNN are optimized by PSO with the objective of maximizing the weld bead integrity and minimizing the weld area. The optimal results are verified on weld profiles, microstructure characteristics, microhardness and tensile strength properties. Due to the limitation of judging the effects of the process parameters on the responses in the optimizing process, the significant factors effects on the integrity and area of weld bead are analyzed based on the signal to noise (S/N) ratio and analysis of variance (ANOVA).

The structure of the paper is organized as follows: The welded joints integrity is analyzed and experimental details to study the weld bead integrity are described in Section 2. Section 3 introduces establishing the relationships between the process parameters and output responses based on GA-BPNN to predict the weld bead integrity and the PSO algorithm used for process parameters optimization. In Section 4, the verification of the proposed optimization method of weld bead integrity on the weld macro profile, microstructure, microhardness and tensile strength properties, and impacts of the process parameters are discussed. The conclusions of the current study are offered in Section 5.

2. Analysis of welded joints integrity and experiments

2.1. The integrity analysis of welded joints

The integrity of the welded joints is highly related to the welding quality and the safe operation in the industrial production [18]. In particular, the dissimilar metals with different thermal conductivity, thermal expansion coefficient and other physical properties are negative for the formation of good joint integrity. Elmesalamy et al. [19] reported that the welded joints with the integrity decreased to 80% failed in the weld bead during the tensile tests. They thought that the weld bead integrity was the highest importance to the final quality of the welded joints. Chen et al. [20] investigated mechanical property of stainless steel/copper laser welding by controlling the process parameters. The joints exhibited fracture at the interface when the laser power was too low and the incomplete fusion defects appeared at the weld bead. The strength of weld bead determines the structural rigidity and durability of welded joints and therefore it plays an important role in influencing the welding quality. The integrity of weld bead is affected by the welding process. Zhang et al. [21] analyzed the associated mechanism of imperfect weld bead such as spatter, underfill and undercut and suggested that the appearance and integrity of copper welded joints could be improved by conducting a high welding speed for full-penetration at the specified laser power. Harooni et al. [22] identified the correlation between the integrity of the weld bead and welding processing condition. Salminen et al. [23] observed that the weld bead integrity would improve and the risk of imperfections would reduce by changing laser power. Therefore, controlling the transmission of the laser energy to the weld zone by adjusting the welding process parameters is very essential to achieve the perfect weld joints. However, increasing the laser energy absorption of metal sheets is beneficial to have a lager weld bead which will result in pore formation and causing a decrease in mechanical properties [22]. The high strengths and ductility of the welded joints are also required proper microstructures by controlling heat treatments strictly. The microstructures are often modified and different from those of the parent metals during the welding process, which reduces the mechanical properties like the strength and ductility [24]. The large weld bead will influence the mechanical and functional properties of welded joints. As a consequence, the good weld bead integrity with minimum weld area is desired in the FLW of dissimilar materials.

In this paper, the optimization method for taking the integrity of weld bead and weld area into comprehensive consideration is proposed. The schematic of the integrity assessment of the weld bead is shown in Fig. 1. From the schematic, it is clear that the imperfections of weld bead are highly related to the height of weld