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ScienceDirect

Defence Technology 12 (2016) 343–350

www.elsevier.com/locate/dt

Optimisation of laser welding parameters for welding of P92 material using Taguchi based grey relational analysis

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Received 3 March 2016; revised 10 April 2016; accepted 11 April 2016

Available online 22 April 2016

Abstract

Creep strength enhanced ferritic (CSEF) steels are used in advanced power plant systems for high temperature applications. P92 (Cr–W–Mo–V) steel, classified under CSEF steels, is a candidate material for piping, tubing, etc., in ultra-super critical and advanced ultra-super critical boiler applications. In the present work, laser welding process has been optimised for P92 material by using Taguchi based grey relational analysis (GRA). Bead on plate (BOP) trials were carried out using a 3.5 kW diffusion cooled slab CO_2 laser by varying laser power, welding speed and focal position. The optimum parameters have been derived by considering the responses such as depth of penetration, weld width and heat affected zone (HAZ) width. Analysis of variance (ANOVA) has been used to analyse the effect of different parameters on the responses. Based on ANOVA, laser power of 3 kW, welding speed of 1 m/min and focal plane at −4 mm have evolved as optimised set of parameters. The responses of the optimised parameters obtained using the GRA have been verified experimentally and found to closely correlate with the predicted value.

Keywords: Laser; Welding; Optimisation; Taguchi; P92

1. Introduction

The global initiative towards “Go Green” has urged all the manufacturing industries to improve the efficiency to reduce the greenhouse gases. In the power sector, it has led to the development of supercritical, ultra super critical and advanced ultra-super critical boiler technologies, which operate at higher temperatures and pressures compared to conventional sub critical boilers. These developments increase the efficiency of operation thereby reducing the polluting emissions and demand the use of materials that can withstand such operating conditions [1]. Stainless steels, Cr–Mo steels like P22, 23, etc., have been traditionally used for such applications in components like super heater tubes, panels, etc. To further increase the life of the components without hampering the heat transfer efficiency, 9–12% Cr steels have been developed, which have better oxidation resistance, high temperature properties, etc. [2]. The most commonly used material in this category is the 9Cr–1Mo (P91) steel due to its high thermal conductivity and low coefficient of thermal expansion compared to the closely competing austenitic stainless steels. P91 has been in use for applications experiencing temperatures of the order of 600 °C [3]. However, the presence of Mo leads to the formation of deleterious phases, which will affect the high temperature performance of the components made of P91 material [4]. To reduce the chance of formation of deleterious phases and to further enhance the high temperature performance, P92 steels have been developed by reducing the Mo content to 0.5% and adding 2% W to compensate for the loss in strength due to reduced Mo content. The material is being considered for applications like headers, panels, coils, etc., in super critical and ultra super critical power plants. P92 materials have oxidation resistance similar to the P91 as the oxidation resistance is influenced by the Cr content and both P91 and P92 materials have similar Cr content. The components fabricated with P92 will involve extensive welding. Hence, weldability of the material will be an essential

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Peer review under responsibility of China Ordnance Society.

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http://dx.doi.org/10.1016/j.dt.2016.04.001
2214-9147/

requirement. P92 is also usually supplied in normalised and tempered conditions and will have fully martensitic microstructure at room temperature and hence, during welding should have issues similar to P91. The weldability issues in the material will include hard and brittle microstructure in weld and HAZ, susceptibility to hydrogen induced cracking (HIC), formation of soft intercritical zone, etc. [5,6]. P91/92 material can be welded by almost all fusion welding processes. Laser welding with the capability of carrying out the welding in open atmosphere with just an inert gas shield is gaining attention for welding of such materials. The use of laser welding can offer benefits like easy shielding of molten pool to avoid hydrogen induced cracking, reduced chances of formation of soft intercritical zone because of high cooling rates associated with the process, reduced chances of formation of deleterious phase, etc. [7,8]. However, there is limited information available in the open literature on laser welding of P92 material. Hence, in the present work, laser welding process has been attempted on P92 plates in bead on plate (BOP) mode.

In any welding process, to achieve the desired properties, it is necessary to carry out the welding using optimised parameters. To obtain the optimised parameters, the scientific method is to use optimisation techniques. In the present work, Taguchi based grey relation analysis method has been used to optimise the parameters. Quite a good number of published literatures have proved the usability of optimisation techniques for both non-fusion and fusion welding including laser welding process of different materials. Ajith et al. [9] have used ANN to optimise friction welding of UNS S32205 duplex stainless steel and Magudeeswaran et al. [10] have optimised ATIG welding parameters using Taguchi followed by ANOVA and Pooled ANOVA to achieve the desired width to depth ratio to avoid hot cracking in the same material. Tamrin et al. [11] have optimised laser lap welding process using grey relational analysis for dissimilar welding of polymer to glass based ceramics to arrive at the optimum joint characteristics like joint strength, etc. and found that welding speed has the maximum influence on the joint characteristics. Zhao et al. [12] optimised laser welding process for welding of thin gauge galvanised steel using response surface methodology (RSM) and they have found that welds made with optimised parameters had good bead geometry values. They could also find out that with optimisation, the process efficiency could be enhanced and the average aspect ratio could be increased from 0.62 to 0.83. Reisgen et al. [13] have optimised CW CO_2 laser welding parameters like laser power, welding speed and focus position using RSM for welding of dissimilar thickness of Advanced High Strength Steels of DP 600 and TRIP steel to achieve good bead geometry parameters, mechanical properties and formability at a reduced cost of fabrication. Olabi et al. [14] have optimised laser welding parameters like laser power, welding speed and focal position using a combined approach with Artificial Neural Network (ANN) and Taguchi analysis to achieve optimal bead geometry values like the ratios of penetration to fusion zone width and penetration to HAZ width. They have arrived at an ANN model that will work for all the range of parameters experimented. Ruggiero et al. [15] have optimised CW CO_2 laser welding parameters using RSM for welding of dissimilar joint involving AISI 316 austenitic stainless steel and low carbon steel to arrive at optimum bead geometry values and welding cost. They have also found welding speed to be the most influencing parameter and the welding cost was found to be greatly reduced based on their devised formula with the optimised parameters. E.M. Anawa and Olabi [16] have used Taguchi approach with ANOVA to arrive at the optimum set of laser welding parameters for achieving good mechanical properties tested by notched tensile specimen for a dissimilar combination of AISI 316 austenitic stainless steel to AISI 1008 low carbon steel. The mechanical properties of welded joints with optimum parameters were found to be better than the base material. They have found laser power to be the most influencing factor in determining the strength of such dissimilar joints. The authors have also optimised the parameters for obtaining good fusion zone properties for the same combination of materials and they have found that with respect to the fusion zone properties, welding speed had the greatest influence [17]. The optimisation technique was found to be a very useful tool even for welding of nonmetals like plastics. Kumar et al. [18] have optimised the laser transmission welding parameters like current, standoff distance and clamping for welding of plastics. Pan et al. [19] used Taguchi method to optimise pulsed Nd:YAG laser welding parameters for welding of AZ31B Magnesium alloy to achieve the maximum tensile strength. The optimisation could yield a parametric combination that could increase the tensile strength by 2.5× compared to the original value as set for laser welding. Benyounis et al. [20] analysed the effect of laser power, welding speed and focal position of the laser beam with respect to the workpiece surface using RSM for CW CO_2 laser welding of medium carbon steel in butt joint configurations. They have concluded that the proposed model could accurately predict the responses like depth of penetration, weld width and HAZ width within the parametric range that have been experimented. All the reported works not only prove the usefulness of the optimisation techniques for optimising the laser welding process for different materials but also prove to be a scientific way to reduce the number of experiments to arrive at a parameter to achieve the desired weld quality.

In the present work, laser welding parameters were optimised using Taguchi analysis with GRA for welding of P92 material using diffusion cooled slab CO_2 laser. The welding trials were carried out using Taguchi L9 orthogonal array in bead on plate (BOP) mode by varying laser power, welding speed and focal position. The trials were carried out twice in a random manner to avoid sequential error. The welds were cut in the transverse direction to study the macrostructure and bead geometry characteristics like depth of penetration, top weld width and HAZ width, which were taken as responses. The average of the responses was taken for the analysis. Subsequently, ANOVA was performed and the optimum parameters were derived. The optimum parameters obtained through the analysis were verified experimentally and the results were presented and discussed.