실험계획법을 이용한 원격 레이저용접 프로세스의 주요 파라미터 도출

Finding principal parameter for remote laser welding processes by using design of experiment

***Kezia Amanda Kurniadi[1], #류광열 [1], 김덕영 [2]**

*K. A. Kurniadi[1], #K. Ryu(kyryu@pusan.ac.kr)[2] , D. Kim[2]

[1] 부산대학교 산업공학과, [2] 울산과학기술대학교 인간및디자인학부

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1. Introduction

Remote Laser Welding (RLW) is emerging as a new laser welding technology in joining process of manufacturing industries. RLW has been proved to have several benefits over another conventional technology, such as Nd:YAG (neodymium-doped yttrium aluminium garnet; Nd:$Y_3Al_5O_{12}$) and CO_2. Those benefits allow RLW to be able to reduce processing time (50-75%), floor factory footprint (50%), environmental impact/energy use (60%), and to provide a flexible base for product changeover.

The most critical obstacle to perform the successful implementation of RLW is the need for tight dimensional control of part-to-part gap during joining operations. This essential quality assurance can be achieved by finding the principal parameters of RLW process[1]. In this paper, a full factorial design of experiment (DOE) was developed to predict welding depth of galvanized mild steel by incorporating three process parameters, such as laser power, welding speed, and focal length. The experimental design was conducted at 95% confidence level, three factors, and three levels at each factor.

2. RLW Machine Characteristic

RLW applies a non-contact process that deploys a high- powered laser to initiate a joint between two disparate parts. The robot arm guides the scanner optics along a smooth path about half a meter over the workpiece[2]. Through program downloading, RLW can run multiple part configurations with quick changeovers[3]. The most essential quality for RLW is based on gap-to-gap dimensional control. RLW machine with KUKA ROBOT KR 150-2 is used and galvanized mild steel as a material. The wave length of beam delivery through disk laser is 1.030μm. The average laser power of the machine is 6.6kW, average focal length as 533mm, and average gas flux as 80lt/min.

3. Statistical Analysis

The parameters considered in RLW joining process are Laser Power (LP), Welding Speed (WS), and Focal Length (FL) in order to discover the welding depth (WD). A three-factor-three-level Box–Behnken statistical design with full replication was used to optimize and evaluate main effects of the RLW process. In statistics, Box-Behnken designs (BBD) are experimental designs for response surface methodology[4]. The three factors for the BBD are designated as x_1, x_2, x_3 and prescribed into three levels coded as +1, 0, -1 for high, medium, and low values, respectively. Three test variables were coded according to the following equation:

$$X_i = \frac{x_i - x_0}{\Delta x} \qquad i = 1,2,3 \tag{1}$$

Where X_i is the coded value of an independent variable, x_i is the actual value of an independent variable; x_0 is the actual value of an independent variable at center point; Δx is the step change value of an independent variable. Table 1 lists the process factors and its levels.

Table 1 RLW process parameters and levels

Parameters	Units	-1	0	+1
Laser Power (LP)	kW	4	6	8
Welding Speed (WS)	m/min	8	14	20
Focal Length (FL)	mm	525	533	541

Moreover, the Minitab software is used to perform the analytical result and the Analysis of Variance (ANOVA) is used to investigate which process parameters significantly affect the quality characteristic[5]. The result of ANOVA is carried out and the results are shown in Table 2. The relative contributions of the parameters can be further discussed by comparing their variances.

Table 2 Results of ANOVA calculations

Source	Goal	F-value	Contribution
LP	Minimize	12.570	17.4%
WS	Maximize	47.200	73.4%
FL	In range	9.122	9.2%

The results of ANOVA calculations above shows that the source which gives the biggest contribution to welding depth is WS (welding speed) with the value of contribution as 73.4%, followed by LP (laser power) with 17.4%, and FL (focal length) with 9.2%. Furthermore, the results of F-test shows that welding depth is significantly affected by the welding speed, since welding speed has the biggest F-value.

4. Conclusion

Based on the experimental results, the process parameter that most significantly affect the welding depth is welding speed, followed by laser power and focal length. A BBD experimental design is utilized for optimization, which replaces the tradition DOE (design of experiment). After conducting the experimental design and analyzing the result, the artificial neural network (ANN) architecture will be able to be built in order to establish the relationship between input parameters and output variables. That model will be developed in MATLAB software and the learning method/algorithm needs to be determined. The proposed plan will be carried out during future research.

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