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International
Journal
Of Modern Engineering Research (IJMER)

Artificial Intelligence based optimization of weld bead geometry in laser welding of Al-Mg alloy sheet

Mr. Manoj Kumar[1], Mrs. Sony Tripathi[2]

[1](Assistant Professor, Department of Mechanical Engineering, Maharana Pratap Engineering College Kanpur, India)

[2](Department of Computer Science & Engg., Naraina College of Engineering & Technology, Kanpur)

ABSTRACT: *This paper reports on a modeling and optimization of laser welding of aluminum-magnesium alloy thickness of 1.7mm. Regression analysis is used for modeling and Genetic algorithm is used for optimize the process parameters.The input values for the regression methods is taken according the Taguchi based orthogonal array. A software named Computer aided Robust Parameter Genetic Algorithm CARPGA has been developed in MATLAB 2013 which combine all of these methodologies. This software has been validated with some published paper.*

Keywords: *Genetic Algorithm, laser welding, orthogonal array.*

I. Introduction

Due to the high efficiency, high energy density, low heat input, large ratio of weld penetration to width, less thermal distortion and easy controlling parameters, Laser Welding process is a promising technology to weld Aluminum based alloy and it has become the most favorable process in industry. LBW is a thermal process in which a high intensity laser beam interacts with the solid surface while resulting in phase change in the irradiated region and melting and evaporation takes place in the heated region.

The ability of Laser beam Welding (LBW) mainly depends on the optical and thermal properties of workpiece materials, and it offers difficulty in processing of materials having relatively high reflectivity and thermal conductivity, such as aluminum and its alloys. These materials are in high demand in various fields of engineering and technology that require complex shapes and geometries in sheet metal components. Also, Problems in dissimilar welding arise from the differences of physical and chemical properties between the welding counterparts and possible formation of intermetallic brittle phases resulting in the degradation of mechanical properties of welds [4].

Various author used the different techniques to optimize the process parameters for weld bead geometry. Vidyut Dey,*et al*. [5] used the Genetic Algorithm to minimize weldment area without sacrificing the quality of the weld.

Mingjun Zhang, Genyu Chen et al.[9] investigated the effect of the processing parameters on the weld appearance of stainless steel plates 12 mm thick using a 10 kW fiber laser and optimal parameters were evaluated. M. Mazar Atabaki et al.[10] used the hybrid laser arc welding for welding of Aluminum alloy sheet. They investigated the joint properties and characteristics of the bonds by the metallographic investigations of the bonds and micro hardness test. They showed that when the offset distance is within the critical distance the laser and arc share the molten pool and specific amount of penetration and dilution can be achieved. Experimental results were compared with simulation.

Taguchi's approach has become one of the most powerful methods of statistical design of experiment (DOE) techniques in recent years. The Taguchi methodology (TM) for robust design is a unique statistical experimental design technique which greatly improves the engineering productivity [7]. In Taguchi Methodology -based experimental studies carried out so far, the experimenters have optimized a single quality characteristic at a time. However, the performance of any manufacturing process depends on many quality characteristics and it is always desired to achieve an optimum parameter level that improves multiple quality characteristics (MQC) at the same time. Dubey A K and Yadava V [7] optimized the three-quality characteristics kerf width, kerf deviation and kerf taper simultaneously using the Taguchi method of Laser cutting process.

In this paper Genetic Algorithm has been applied to investigate the optimum parameter settings for welding of Aluminum-Magnesium alloy sheet (a difficult to laser cut material). The controllable factors taken are laser power, welding speed and wire feed whereas the quality characteristics analyzed are upper width U, lower width L and fusion zone area . Hybrid software named, Computer aided Robust Parameter Genetic Algorithm (CARPGA) software has been developed in MATLAB. This software has been used for selection of appropriate experimental design matrix or orthogonal array (OA) and Multi-objective optimization of Laser welding process parameters. The experimental data is taken from the literature [6].

II. Experimental planning method

The experimental data's were modified by taking different orthogonal arrays and then linear model were developed by using Regression analysis. And these equations were used as objective functions for genetic algorithm.

2.1 selection of orthogonal array

The selection of OA is based on the total degree of freedom (dof) of the process. The minimum number of experiment required for certain control factors is equal to the Degree of freedom. Mathematically, the dof can be computed as [7]:

DOF = (number of levels-1) for each control factor + (number of levels for P-1) × (number of levels for Q-1) for each interaction +1

Where P and Q are control factors.

2.2 Regression Analysis

Regression analysis is a statistical technique for investing and modelling the relationship between variables. If y is a single dependent variable or response and x_1, x_2, x_3,……., x_k are the independent or regressor variables, then a mathematical model that might describe this relationship is;

$$y_j = b_0 + \sum_{i=1}^{k} b_i x_i + \sum_{i=1}^{k} b_{ij} x_i^2 + \sum_{i} \sum_{j} b_{ij} x_i x_j \quad ……(i)$$

Multivariable linear regression (MVLR) analysis was used here and these model equations were used in GA. In this case, there are three independent variables and three dependent variables.

2.2 Genetic Algorithm

Genetic algorithms are computerized search and optimization algorithms based on the mechanics of natural genetics & natural selection that can be used to obtain global and robust solution to optimization problems. GA produces ever-improving solutions based on the rule 'the best one survives'. For this purpose, it uses a fitness function that selects the best and operators like regeneration and mutation to produce new solutions.

GA's identify a set of solutions of a given problem that are close to the optimum solution. It can be employed linear as well as nonlinear optimization problems. Therefore, it can be used to find multiple optimal solutions simultaneously in multi-objective optimization problems [8].

In this research work, upper width U, lower width L and fusion zone area are the objective functions and all of three have been optimized simultaneously.

III. Development of software & validation

Hybrid software named, Computer aided Robust Parameter Genetic Algorithm (CARPGA) software has been developed in MATLAB. This software automatically selects the orthogonal array, develop a mathematical model for output characteristics and optimize the process parameters simultaneously. This software was validated by some published paper [7,11]. Dubey, Yadava [7] developed a software named computer aided robust parameters design to optimize the kerf width and MRR of laser cutting process.

Table 1: Comparison between the published result and software result [7]:

	Input parameters				Output characteristics	
	Oxygen pressure (kg/cm^2)	Pulse width (ms)	Pulse frequency (HZ)	Cutting speed (mm/min)	Kerf Taper (degree)	MRR (mg/min)
Published result	4	1.2	28	7.5	0.2295	12.193
Software result	4.3	1.23	27.32	8.01	0.1795	13.01

Sharma et al.[11] used Taguchi and Grey relational analysis to optimize the laser cutting processes. Objective was to minimize the average kerf taper and average surface roughness. From table 2 It can be seen that on given input parameters, the output characteristics give better result.

Table 2: Comparison between the published result and software result [11]

	Input parameters				Output characteristics	
	Oxygen pressure (kg/cm^2)	Pulse width (ms)	Pulse frequency (HZ)	Cutting speed (mm/min)	Average kerf taper (degree)	Average surface roughness Ra (µm)
Paper result	6	1.8	10	8	0.1255	1.7
Software result	5.5	2.1	9.5	7.32	0.1001	1.45

From the above validations, it proved that the proposed developed software give the better result compares to published result. Therefore, this software can be used to our foregoing optimization problem.

IV. Multi objective optimization using Carpga

The original Taguchi method has been applied to develop L_{18} orthogonal array which is listed in table3. Because it gives the randomized values for process parameters to conduct the experiment [3].

Table 3: Experimental layout using L_{18} orthogonal array

Input Parameters			Corresponding output characteristics		
Laser power	Welding speed	Wire feed speed	Upper width	Lower width	Fusion zone area
2.4	1.5	2	4.32	3.76	6.79
2.4	1.5	5	3.79	2.35	6.37
2.4	1.5	8	3.57	3.21	6.78
2.4	2.1	2	3.76	3.41	5.27
2.4	2.1	5	4.76	1.7	7.42
2.4	2.1	8	4.45	1.34	7.48
2.4	3	2	3.75	2.52	4.98
2.4	3	5	3.76	2.49	6.54
2.4	3	8	4.27	3.1	5.67
2.6	1.5	2	4.19	3.41	6.72
2.6	1.5	5	5.7	1.75	6.66
2.6	1.5	8	5.43	1.34	6.67
2.6	2.1	2	4.32	2.3	6.78
2.6	2.1	5	3.17	2.34	5.92
2.6	2.1	8	3.21	2.31	7.27
2.6	3	2	3.25	2.23	7.78
2.6	3	5	3.23	3.1	4.78
2.6	3	8	4.23	3.2	6.58

4.2 Modeling

The mathematical model equations developed for upper width (U), lower width (L) and the Fusion zone Area (A) by the software are:

$$\text{Upper width (U)} = 4.4831+0.1667\times A - 0.4785\times B + 0.0436\times C \quad \text{.....(ii)}$$

$$\text{Lower width (L)} = 5.3326 - 1.0556\times A + 0.1313\times B - 0.0869\times C \quad \text{.....(iii)}$$

$$\text{Fusion zone area} = 4.5374 + 1.0333\times A - 0.4303\times B + 0.0592\times C \quad \text{.....(iv)}$$

Where A,B,C are laser power, welding speed and wire feed speed respectively.

4.3 Optimization

The developed equations for upper width (U), lower width (L) and the Fusion zone Area (A) were used as objective function in Genetic Algorithm. In the Genetic Algorithm optimization we get the some sets of optimized result. Among these we generally select the set of result according to our aim (i.e. objective is maximization or minimization). Here our objective is to minimize the upper width, lower width and fusion zone area. Therefore, the objective functions and their constraints used are given below;

Minimize:

Upper width (U):

Fun(1) = 4.4831+0.1667×laser power – 0.4785 × welding speed + 0.0436 ×wire feed speed

Lower width (L):

Fun(2) = 5.3326 – 1.0556 × laser power + 0.1313× welding speed – 0.0869× wire feed speed

Fusion Size (F):

Fun(3) = 4.5374 + 1.0333 ×laser power – 0.4303×welding speed + 0.0592 × wire feed speed

Subjected to:

$2.4 \leq$ laser power ≤ 2.8

$1.5 \leq$ welding speed ≤ 3

$2 \leq$ wire feed speed ≤ 8

V. Results and discussions

The set of multi-objective optimization results obtained by CARPGA are shown in Table 4. The population size = 250, mutation rate = 0.5, and double point cross over were selected as genetic algorithm parameters. These parameters were chosen by trial and error method. The score diversity of three objectives are shown in fig.1.

In genetic algorithm we get a set of results. Actually our aim is to minimize the objectives, so we have selected the minimized value of upper width, lower width and fusion zone area are 3.2 mm, 2.89mm and 5.73 mm respectively. From the figure 2, we can say that the optimization is healthy since the value of pareto spread is very low.

Table 4. Optimum result of process parameters using CARPGA

Laser power(kW)	Welding Speed (m/min)	Wire feed speed (m/min)	Upper width (mm)	Lower width (mm)	Fusion zone size (mm)
2.4	2.998	6.170	3.716	2.656	6.092
2.4	2.992	3.8769	3.619	2.855	5.95
2.4	2.831	7.975	3.875	2.40	6.27
2.4	**2.99711**	**3.490**	**3.200**	**2.189**	**5.73**
2.4	1.6499	7.965	4.440	2.323	6.77
2.4	1.5736	7.976	4.477	2.312	6.81
2.4	2.9893	2.454	3.558	2.978	5.87
2.4	1.7650	7.973	4.385	2.337	6.72
2.4	2.7325	7.987	3.923	2.463	6.31
2.4	2.9996	3.731	3.609	2.868	5.94
2.4	1.7549	7.983	4.391	2.335	6.73
2.4	2.9970	3.083	3.582	2.924	5.91
2.4	2.9790	2.523	3.566	2.971	5.88
2.4	2.9893	4.117	3.631	2.833	5.97
2.4	1.5021	7.995	4.512	2.301	6.84
2.4	2.9975	7.833	3.789	2.511	6.19
2.4	2.8237	7.986	3.879	2.475	6.27
2.4	2.0652	7.987	4.242	2.376	6.60
2.4	2.9951	3.642	3.608	2.875	5.94
2.4	2.9793	7.933	3.802	2.500	6.20
2.4	2.6211	7.979	4.397	2.334	6.74
2.4	1.7419	7.983	4.292	2.362	6.64
2.4	1.9621	7.988	3.769	2.558	6.16
2.4	2.9899	7.283	4.482	2.309	6.81
2.4	1.5643	7.996	3.803	2.505	6.20

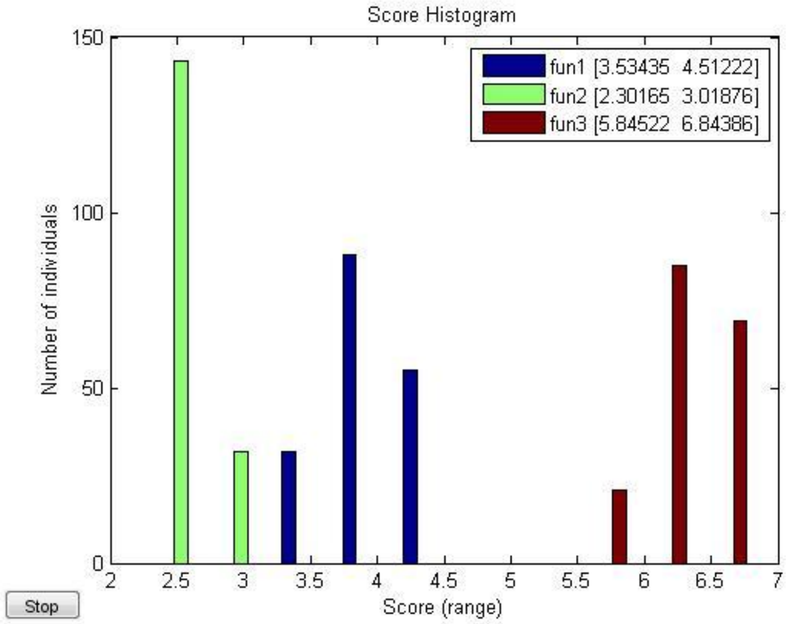

Fig.1. Score diversity of the upper width, lower width and fusion zone area

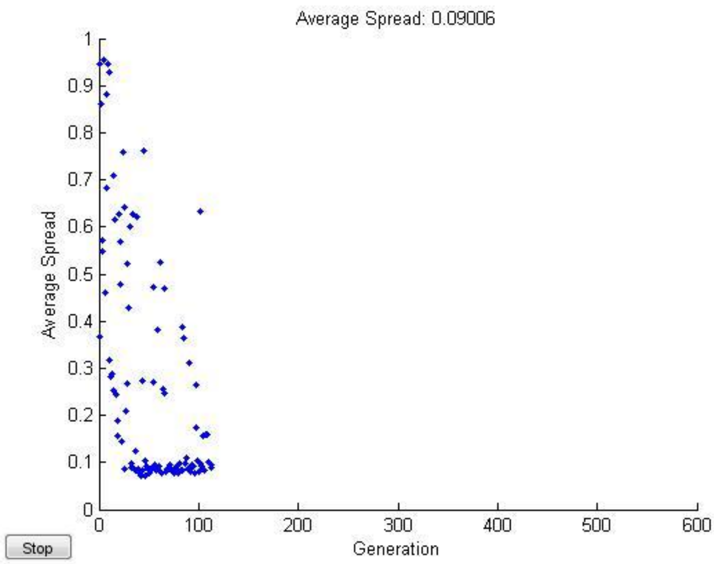

Fig.2. Variation of Avereage pareto spread with number of generations

VI. Conclusions

In this paper, hybrid software was developed and this was used to optimize the laser welding process. It was found that at laser power =2.4 kW, welding speed =2.9971m/min, and wire feed rate =3.49, the optimal values of upper width=3.2, lower width =2.189mm, and fusion zone area =5.73 mm respectively, which is agreed well with experimental result. It was also found that welding speed is most influent parameter. . It can be concluded that proposed CARPGA approach is efficient and gives the promising results. The heuristic is also found to give better solutions in shorter computational time

Acknowledgements

We offer our sincerest gratitude to our friend, Mr. Sanjay Kumar, Research scholar, IIT Kanpur, who has provided the needful help in developing the coding in MATLAB.

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