Int. J. Enterprise Network Management, Vol. 12, No. 1, 2021

Improving mechanical strength on welded joints by using optimisation technique

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Abstract: The welding process is an important component in many industrial operations. Welding input parameters play a very significant role in determining the quality of a weld joint. The joint quality can be defined in terms of properties such as weld-bead geometry, mechanical properties, and distortion. Generally, all welding processes are used with the aim of obtaining a welded joint with the desired weld-bead parameters, excellent mechanical properties with minimum distortion. So that in this paper presents find the suitable input parameter in welded joints and then find the full penetration of the material. By using on design of experiment (DOE), genetic algorithm and computational network are widely used to develop a mathematical relationship between the welding process input parameters and the output variables of the weld joint in order to determine the welding input parameters that lead to the desired weld quality of the welded material.

Keywords: welding; design of experiment; DOE; parameter optimisation; GA; regression equation.

Reference to this paper should be made as follows: Pandiyarajan, R. (2021) 'Improving mechanical strength on welded joints by using optimisation technique', *Int. J. Enterprise Network Management*, Vol. 12, No. 1, pp.85–96.

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This paper is a revised and expanded version of a paper entitled 'International conference on modeling, optimization and computing' presented at International Conference on Modeling, Optimization and Computing, Noorul Islam University, Kumaracoil, India, 10–11 April 2014.

1 Introduction

Welding is defined as a process where two or more pieces of metal or thermoplastics are fastened together by use of heat and pressure. The process of applying heat softens the material and enables it to affix together as one in a joint area when an adequate amount of pressure is applied. The concept of welding first developed in the middle ages, though it did not form into the process of welding as it is today until the latest years of the 19th century. Before this, a process known as 'forge welding' was the only means of joining two metal objects together. Forge welding consisted of using a flame to heat metal to extremely high temperatures and then hammering each piece together until they became one. This method was replaced around the time of the industrial revolution. Electric and gas flame heating methods proved to be much safer and faster for welders. Practically, every material object that has made society what it is today, was created by welded construction tools or has been welded itself. Because of this, welders have a wide range of areas for employment; many welders specialise in pipe welding or automobile welding while others specialise in machinery.

The possibilities are endless for welders seeing as welding can be performed in a diverse range of locations, including underwater, though not all forms of welding are the same. Some forms of welding use gas, while others use electric and the newest forms involve use of a laser. The process of welding that is used depends on a variety of factors but the form and thickness of the material is usually the deciding factor for which method is most effective. Maximum quality is assured by maintaining the cleanliness of the operation – all equipment and materials used must be free from oil, moisture, dirt and other impurities, as these cause weld porosity and consequently a decrease in weld strength and quality. To remove oil and grease, alcohol or similar commercial solvents may be used. The concentrated nature of the arc is one of its strong points. Welds of great strength and quality can be made with thin materials, light materials, dissimilar materials, in most available metals, and all with minimal distortion or corruption of the adjoining base metal. However, welding does have disadvantages. Low heat input, caused by low welding current or high welding speed, can limit penetration and cause the weld bead to lift away from the surface being welded. Conversely, too much heat input causes the weld bead to grow in width while the likelihood of excessive penetration (burn-through) and spatter increase.

Manual GTAW is often considered the most difficult of all the welding processes commonly used in industry since great care and skill are required to control the amount of current used, and prevent Contact between the electrode and the work piece, while maintaining a short arc length. Although some welds combining thin materials can be accomplished without filler metal (known as autogenous welds), unlike other welding processes, GTAW normally requires two hands; since most applications require that the welder manually feed a filler metal into the weld area with one hand while manipulating the welding torch in the other. These disadvantages can be avoided by automating the welding process and so this option is very favourable. Theoretically, an extremely thin fused layer might be sufficient for connecting the parts to be joined. The fusion layer should not be thicker than necessary in order to avoid wasting of energy, edge burn-off, sagging of the weld pool and deep weld end craters (Gunaraj and Murugan, 1999). Control of weld bead shape is essential since this shape has a direct effect on the mechanical properties of the weld (Juang and Tarng, 2002). Therefore, it is clear that precise selection of the process Parameter is necessary. The principle operating variables for GTAW are:

- arc voltage (arc length)
- welding current
- welding speed (and filler wire feed rate if applicable)
- shielding gas (inert gas such as argon or helium).

All of these variables interact with each other very strongly; therefore, they cannot be treated as independent variables while establishing welding procedures for fabricating specific joints.

The common approaches to tackle optimisation problem in welding include multiple regression analysis, response surface methodology (RSM), artificial neural network (ANN) modelling and Taguchi method (Juang and Tarng, 2002; Kannan and Murugan, 2006; Kim et al., 2003; Koleva, 2001). In most of the cases the optimisation has been performed using single objective function. For a multi-response process, while applying the optimal setting of control factors, it can be observed that an increase/improvement of one response may cause change in another response, beyond the acceptable limit. Thus for solving multi-criteria optimisation problems, it is convenient to convert all the objectives into an equivalent single objective function. This equivalent objective function, which is the representative of all the quality characteristics of the product, is to be optimised (maximised). The Taguchi method is very popular for solving optimisation problems in the field of production engineering (Maghsoodloo et al., 2004; Mandal, 2004). The method utilises a well-balanced experimental design (allows a limited number of experimental runs) called orthogonal array design, and signal-to-noise ratio (S/N ratio), which serve the objective function to be optimised (maximised) within experimental domain. However, traditional Taguchi method cannot solve multi-objective optimisation problem. To overcome this, the Taguchi method coupled with Grey relational analysis has a wide area of application (Murugan and Parmar, 1994). This approach can solve multi- response optimisation problem simultaneously. It is appropriate to apply this technique to a complex system like welding process. Apart from process optimisation, it is necessary to determine the degree of significance of the factors on the output features of the final product. This statistical significance of the factors can be evaluated through analysis of variance (ANOVA).

The present work genetic algorithms are used for optimising the welding process parameters with respect to desired front height and front width and back height and back width of the weld beads. Program formulation and execution of genetic algorithms In the present work, genetic algorithm is used to optimise the welding process parameters for the set desired values of front height to front width ratio and back height to back width ratio of the weld beads obtained during welding experiments listed Program formulation for this purpose had been made using various functions of the GA toolbox on MATLAB platform, so that the GA can generate a set of population, which can reproduce and cross among themselves to create a best possible solution.

2 Literature review

Sanders et al. (1977) has done temperature dependent deformation mechanisms of alloy 718 in low cycle fatigue, at high strain ranges the lowest fatigue life was exhibited at the higher temperatures. However, in the low strain, long life regime this trend reversed with the fatigue life at a given strain range exhibiting a peak at some intermediate temperature. transmission electron microscopy (TEM) and scanning electron microscopy (SEM) studies were conducted on the fatigue specimens to determine the nature of the cyclic deformation process as a function of strain range and temperature, the principal mode of deformation was by mechanical twinning. However, at the two highest temperatures, the primary process for deformation was slip. The principal difference between the strain-life behaviour of the specimens cycled at 538 and 649°C, and those cycled at the three lower temperatures (204, 316, 427°C) is interpreted in light of this change in deformation process with temperature.

Fournier and Pineau (1977) has done low cycle fatigue behaviour of Inconel 718 at 298 K and 823 K, a substantial decrease in fatigue life occurred as the temperature was increased from 298 to 823 K and as the cycling frequency was lowered from 3 cycles Jmin to 0.3 cycles Jmin at 823 K. At 298 K, for all the strain amplitudes investigated, an initial rapid hardening was followed by softening, while at 823 K only softening occurred. Electron microscopy showed that the precipitates were sheared in the course of cyclic straining and that plastic deformation proceeded by the propagation of planar bands. These bands were identified as twins. Twinning was found to be more abundant at elevated temperatures than at room temperature, especially at lower frequencies. Cracking was generally initiated along the interfaces between these twin bands and the matrix but, at elevated temperatures and low strain rates, inter crystalline cracking took place, as well. The influence of particles shearing and twinning on the cyclic stress-strain response of the material are discussed. The importance of planar deformation and twinning on inter granular cracking is emphasised.

Ghonem and Zheng (1992) has done elevated temperature fatigue crack growth in alloy 718 – part 1: effects of mechanical variables. In this paper observations concerning the effects of mechanical variables on the crack growth process in alloy 718 are reviewed and analysed on the basis of the related deformation characteristics in the crack tip region. The variables included temperature, frequency, wave shape, hold time, load ratio and load interaction. These analyses have suggested that the role of each parameter in the acceleration of crack tip damage is governed mainly by their relative influence on the nature of the corresponding plastic deformation and associated slip line density. On the basis of this view (which assumes crack growth damage covers the range from cyclic- to fully time-dependent processes), the interactive effects of loading parameters are discussed when considering the corresponding fracture mode. Conflicting experimental observations under different operating conditions are examined.

Rao et al. (1998) has done influence of time and temperature dependent processes on strain controlled low cycle fatigue behaviour of alloy 617, A reduction in fatigue life was observed with decreasing ε at 850°C and with increasing temperature at $\varepsilon = 4 \times 10_{-5}\ {}_{s-1}$. Cyclic stress response varied as a complex function of temperature and strain rate. Fatigue deformation was found to induce cellular precipitation of carbides at 750 and

850. Dynamic strain aging characterised by serrated flow was observed at 750°C ($\varepsilon = 4 \times 1_{0-5\ s-1}$) and in the tests at higher ε at 850°C. Strengthening of the matrix due to dynamic strain aging of matrix dislocations by precipitation of M23C6 carbides led to fracture of grain boundary carbide films formed at 750°C, producing brittle inter granular crack propagation. At 850°C trans granular crack propagation was observed at the higher strain rates $\varepsilon \geq 4\times 10_{-4\ s-1}$. At 850 and 950°C even at strain rates of $4 \times 10_{-5\ s-1}$ or lower, life was not governed by inter granular creep rupture damage mechanisms under the symmetrical, continuous cycling conditions employed. Reduction of endurance at lower strain rates are caused by increased inelastic strain and inter granular crack initiation due to oxidation of surface connected grain boundaries.

Nagesh and Datta (2002) has done generic algorithm for optimisation of welding variables for height to width ratio and application of ANN for prediction of bead geometry for TIG welding process. This explains an integrated method with a new approach using experimental matrix of experimental designs technique on the experimental data available from conventional experimentation, application of neural network for predicting the weld bead geometric descriptors and use of generic algorithm for optimisation of process parameters. Modelling of weld bead shape is important for predicting the bead shape parameters of welded joints, modelling and optimisation of bead shape parameters in tungsten inert gas (TIG) welding process has been tried.

Dutta and Pratihar (2007) has done modelling of TIG welding process using conventional regression analysis and neural network-based approaches, conventional regression analysis was carried out some experimental data of a TIG welding process (obtained from published literature), to find its input-output relationships. One thousand training data for neural networks were created at random, by varying the input variables within their respective ranges and the responses were calculated for each combination of input variables by using the response equations obtained through the above conventional regression analysis. The performance of the conventional regression analysis approach, a back propagation neural network (BPNN) and a genetic – neural system (GA-NN) were compared on some randomly generated test cases (experimental), which are different from the training cases. It is interesting to note that for the said test cases, the NN-based approaches could yield predictions that are more adaptive in nature compared to those of the more conventional regression analysis approach.

2.1 Inference from literature survey

From the literature review is mainly concerned with welding, the residual stresses and distortions it produces and their mitigation, process modelling of welding (with a focus on computational application) for the prediction of residual stress and distortion, and it concludes with a section on material, welding and the understanding that can be attained by modelling the process are very important fields in engineering and also selection of welding parameters which are most dominant process variables in the result of best weld in an engineering applications.

3 Fractional factorial doe technique

It is a common practice to develop regression equations using either conventional experimental data or by using experimental data obtained with the help of design of experiments (DOEs) technique. In the present work for developing the regression equations and for modelling and optimising the process parameters of welding process, experimental data were selected. The selection of data is based on design matrix 2_{n-1} fractional factorial DOEs.

Table 1 Experimental variable levels

Experimental variables	*Maximum*	*Minimum*
S	24	46
WS	1.5	2.5
CP	30	70
C	80	110
G	2.4	3.

Table 2 Trials and welding conditions

Trials	*S*	*WS*	*CP*	*C*	*G*
1	24	1.5	30	80	3.2
2	46	1.5	30	80	2.4
3	24	2.5	30	80	2.4
4	46	2.5	30	80	3.2
5	24	1.5	70	80	2.4
6	46	1.5	70	80	3.2
7	24	2.5	70	80	3.2
8	46	2.5	70	80	2.4
9	24	1.5	30	110	2.4
10	46	1.5	30	110	3.2
11	24	2.5	30	110	3.2
12	46	2.5	30	110	2.4
13	24	1.5	70	110	3.2
14	46	1.5	70	110	2.4
15	24	2.5	70	110	2.4
16	46	2.5	70	110	3.2

In this method –n|| means the number of WPVs. For determining the five main variable effects and ten two factor interaction effects only 16 trials needed. As per the DOEs convention the low level of a variable is designated by –1 and high level by +1. The standard variables and denoted by X1, X2, X3, X4 and X5. The variables affected by the standard variables are denoted by FH, FW, BH and BW. The resulting table is trials and standardised variables (Tables 1 to 3)

Table 3 Different welding process parameter

Trials	*X1*	*X2*	*X3*	*X4*	*X5*	*X12*	*X13*	*X14*	*X15*	*X23*	*X24*	*X25*	*X34*	*X35*	*X40*
1	–1	–1	–1	–1	1	1	1	1	–1	1	1	–1	1	–1	–1
2	1	–1	–1	–1	–1	–1	–1	–1	–1	1	1	1	1	1	1
3	1	1	–1	–1	–1	–1	–1	1	1	1	–1		1	1	1
4	1	1	–1	–1	1	1	–1	–1	1	–1	–1	1	1	–1	–1
5	–1	–1	1	–1	–1	1	–1	1	1	–1	1	1	–1	–1	1
6	1	–1	1	–1	1	–1	1	–1	1	–1	1	–1	–1	1	–1
7	–1	1	1	–1	1	–1	–1	1	–1	1	–1	1	–1	1	–1
8	1	1	1	–1	–1	1	1	–1	–1	1	–1	–1	–1	–1	1
9	–1	–1	–1	1	–1	1	1	–1	1	1	–1	1	–1	1	–1
10	1	–1	–1	1	1	–1	–1	1	1	1	–1	–1	–1	–1	1
11	–1	1	–1	1	1	–1	1	–1	–1	–1	1	1	–1	–1	1
12	1	1	–1	1	–1	1	–1	1	–1	–1	1	–1	–1	1	1
13	–1	–1	1	1	1	1	–1	–1	–1	–1	–1	–1	–1	1	1
14	1	–1	1	1	–1	–1	1	1	–1	–1	–1	1	1	–1	–1
15	–1	1	1	1	–1	–1	–1	–1	1	1	1	–1	1	–1	–1
16	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

3.1 Regression equation for bead shape parameters

For each of these features, linear regression equations were obtained by considering both main and two factor interaction effects. To obtain these equations, the experimental conditions presented in table and the experimental results presented in table were used. Weld bead shape features were then computed from these linear regression equations and compared with actual experimental values.

- Equation for front height:

$$\begin{aligned} \mathrm{Y1} = {} & \mathrm{a0} + \mathrm{a1X1} + \mathrm{a2X2} + \mathrm{a3X3} + \mathrm{a4X4} + \mathrm{a5X5} + \mathrm{a6X12} + \mathrm{a7X13} + \mathrm{a8X14} \\ & + \mathrm{a9X15} + \mathrm{a10X23} + \mathrm{a11X24} + \mathrm{a12X25} + \mathrm{a13X34} + \mathrm{a14X35} + \mathrm{a15X45} \end{aligned}$$

- Equation for front width:

$$\begin{aligned} \mathrm{Y2} = {} & \mathrm{b0} + \mathrm{b1X1} + \mathrm{b2X2} + \mathrm{b3X3} + \mathrm{b4X4} + \mathrm{b5X5} + \mathrm{b6X12} + \mathrm{b7X13} + \mathrm{b8X14} \\ & + \mathrm{b9X15} + \mathrm{b10X23} + \mathrm{b11X24} + \mathrm{b12X25} + \mathrm{b13X34} + \mathrm{b14X35} + \mathrm{b15X45} \end{aligned}$$

- Equation for back height:

$$\begin{aligned} \mathrm{Y3} = {} & \mathrm{c0} + \mathrm{c1X1} + \mathrm{c2X2} + \mathrm{c3X3} + \mathrm{c4X4} + \mathrm{c5X5} + \mathrm{c6X12} + \mathrm{c7X13} + \mathrm{c8X14} \\ & + \mathrm{c9X15} + \mathrm{c10X23} + \mathrm{c11X24} + \mathrm{c12X25} + \mathrm{c13X34} + \mathrm{c14X35} + \mathrm{c15X45} \end{aligned}$$

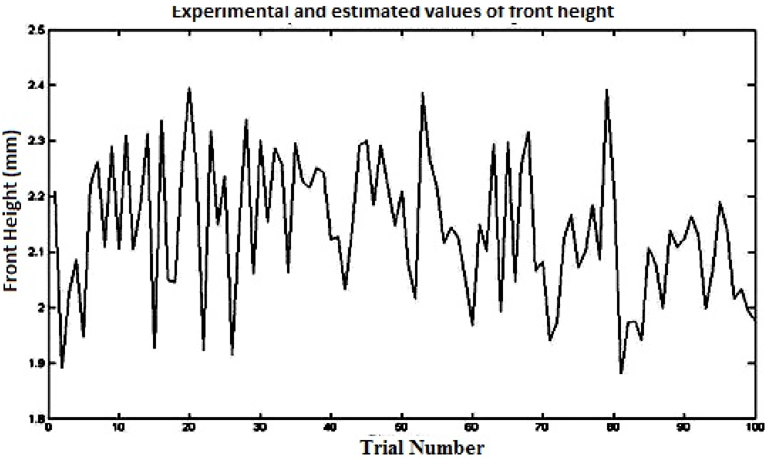
- Equation for back width:

$$Y4 = d0 + d1X1 + d2X2 + d3X3 + d4X4 + d5X5 + d6X12 + d7X13 + d8X14 \\ + d9X15 + d10X23 + d11X24 + d12X25 + d13X34 + d14X35 + d15X45$$

4 Bead shape parameter – front height – 100 trials

A possible solution can get by a given number of generations. In the GA program for optimising the process parameters of Welding process to get the desired values of front height i.e., the desired appropriate objective function has been defined.

Figure 1 No. of trials vs. front height (100 trials)

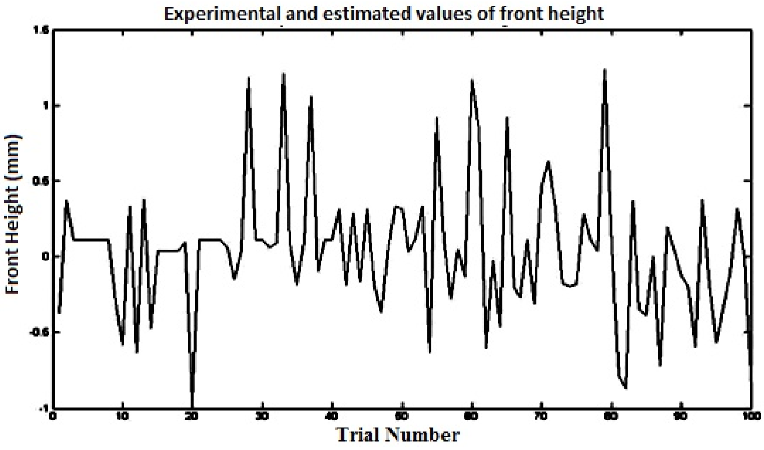


The goal of this section is to obtain the optimised process parameters for the desired values using genetic algorithm. The experimental conditions for this investigation are taken from the table and the values are calculated from the bead shape parameters are presented. As shown in Figure 1.

4.1 Bead shape parameter – front width – 100 trials

A possible solution can get by a given number of generations. In the GA program for optimising the process parameters of Welding process to get the desired values of Front width i.e., the desired appropriate objective function has been defined. The goal of this section is to obtain the optimised process parameters for the desired values using genetic algorithm. The experimental conditions for this invesation are taken from the table and the values are calculated from the bead shape parameters are presented. As shown in Figure 2.

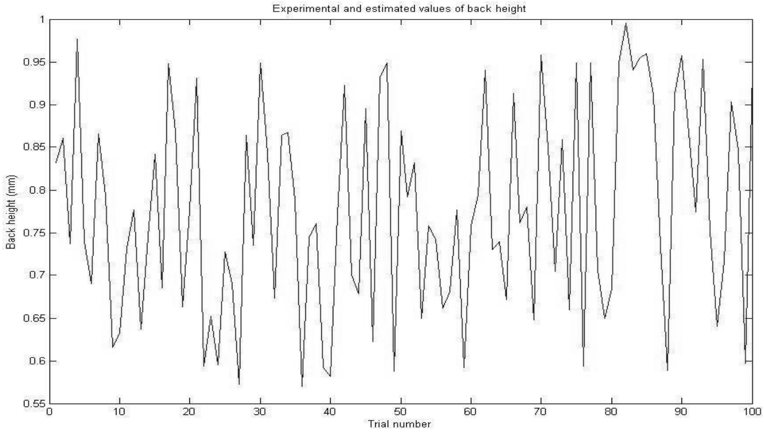
Figure 2 No of trials vs. front width (100 trials) (see online version for colours)



4.2 *Bead shape parameter – back height – 100 trials*

A possible solution can get by a given number of generations. In the GA program for optimising the process parameters of Welding process to get the desired values of back height i.e., the desired appropriate objective function has been defined. The goal of this section is to obtain the optimised process parameters for the desired values using Genetic Algorithm. The experimental conditions for this invesation are taken from the table and the values are calculated from the bead shape parameters are presented. As shown in Figure 3.

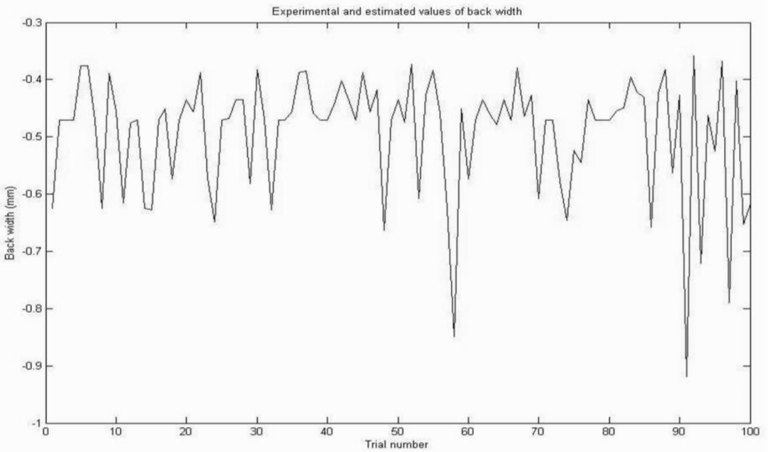
Figure 3 No. of trials vs. back height (100 trials) (see online version for colours)



4.3 *Bead shape parameter – back width – 100 trials*

A possible solution can get by a given number of generations. In the GA program for optimising the process parameters of Welding process to get the desired values of back width i.e., the desired appropriate objective function has been defined. The goal of this section is to obtain the optimised process parameters for the desired values using Genetic Algorithm. The experimental conditions for this invesation are taken from the table and the values are calculated from the bead shape parameters are presented. As shown in Figure 4).

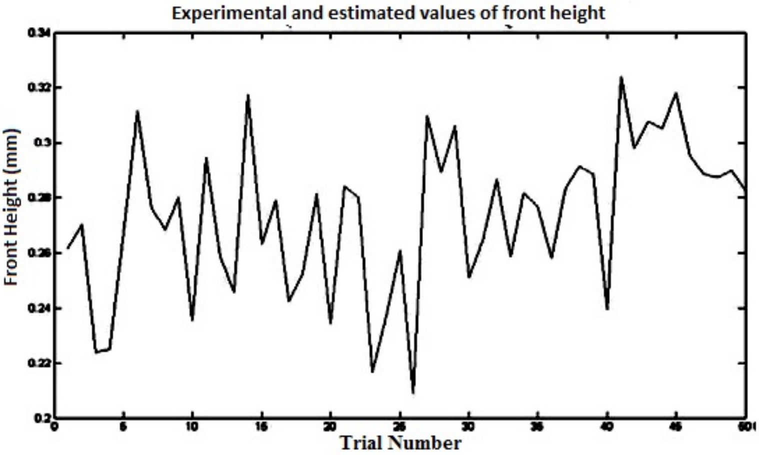
Figure 4 No. of trials vs. back width (100 trials)



4.4 Bead shape parameter – front height – 50 trials

The goal of this section is to obtain the optimised process parameters for the desired values using Genetic Algorithm. The experimental conditions for this invesation are taken from the table and the values are calculated from the bead shape parameters are presented. As shown in Figure 5.

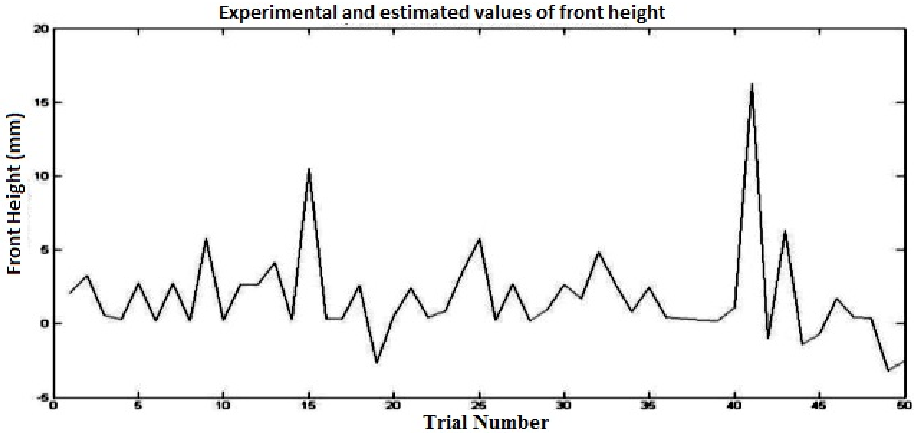
Figure 5 No. of trials vs. front height (50 trials) (see online version for colours)



4.5 Bead shape parameter – front width – 50 trials

A possible solution can get by a given number of generations. In the GA program for optimising the process parameters of Welding process to get the desired values of front width i.e., the desired appropriate objective function has been defined. The goal of this section is to obtain the optimised process parameters for the desired values using genetic algorithm. The experimental conditions for this invesation are taken from the table and the values are calculated from the bead shape parameters are presented. As shown in Figure 6.

Figure 6 No. of trials vs. front width (50 trials)



5 Conclusions

Welding process parameters are optimised using GA, separately for front height to front width ratio and back height to back width ratio. Optimal process parameters were searched by the genetic algorithm to arrive at the desired front height to front width ratio and back height to back width ratio. The results of GA are summarised.

The results indicate that all the five independent controllable process variables, which were optimised by the GA are having values between the vectors of minimum and maximum values of the controllable process variables. This is true for both the front height to front width ratio and back height to back width ratio cases. With these results, it is found that GA can be a powerful tool in experimental welding optimisation.

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