Optimization of FCAW process parameters using a non-traditional technique

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ABSTRACT

Weld cladding is a process of depositing a thick layer of metal surface to a carbon steel base metal for the purpose of providing a corrosion resistant surface when that surface is to be exposed to a corrosive environment. In cladding process, most of the engineers often face the problem of selecting optimum combination of input process parameters for achieving the required clad quality. This problem can be solved by using Genetic Algorithm (GA) technique to optimize the process parameters to achieve minimum dilution and penetration, maximum bead width and reinforcement. This paper focuses on an optimization of input process parameters in duplex stainless steel cladding of low carbon structural steel plates deposited by Flux Cored Arc Welding (FCAW).

Key Words: Optimization, FCAW, Genetic Algorithm, Duplex Stainless Steel, MATLAB

INTRODUCTION

Weld cladding is an excellent way to impart properties to the surface of a base metal. Typical base metal components that are weld cladded include the internal surfaces of carbon steel pressure vessels used in chemical, fertilizer, food processing and petrochemical plants. The biggest difference between welding a joint and cladding is dilution. Dilution reduces the alloying elements and increases the carbon content in clad layer which reduces corrosion resistance properties, and causes other metallurgical problems [1]. The composition and properties of cladding are strongly influenced by the dilution obtained. Control of dilution is very important in cladding, where low dilution is typically desirable.

Various welding processes employed for cladding are Shielded Metal Arc Welding, Submerged Metal Arc Welding, Gas Tungsten Arc Welding, Plasma Arc Welding, Gas Metal Arc Welding, Flux Cored Arc Welding, Electroslag Welding, Oxy-Acetylene Welding and Explosive Welding.

This paper highlights an optimization of percentage dilution in FCAW. It was carried out using Genetic Algorithm technique available in optimization tool box of MATLAB 7 software.

GENETIC ALGORITHM

Optimization is a collective process of determining a set of conditions required to achieve the best results form a given situation [2].

The idea of applying the biological principle of natural evolution to artificial systems, introduced more than three decades ago, has seen impressive growth in the past few years. The basic concept of Genetic Algorithm is to encode a potential solution to a problem as a series of parameters. A single set of parameter value is treated as the genome of an individual solution. An initial population of individuals is generated at random or statistically.

Every evolutionary step, known as a generation, the individuals in the current population are decoded (evaluated) according to some predefined quality criterion, referred to as fitness function. The chromosomes with the highest population fitness score are selected for mating. The genes of the two parents are allowed to exchange to produce offsprings. These children then replace their parents in the next generation. Thus, the old population is discarded and the new population becomes the current population. The current population is checked for acceptability of solution. The iteration is stopped after the completion of maximal number of generations or on the attainment of the best result.

Basic Description of Genetic Algorithm

The Genetic Algorithms are inspired by Darwin's theory about evolution [2]. Algorithm is started with a set of solutions from one population are taken and used to form a new population. This is motivated by a hope, that the new population will be better than the old one. Solutions which are selected to form new solutions are selected according to their fitness. The more suitable they are, the more chances they have to reproduce.

This is repeated until some conditions are satisfied.

Basic Genetic Algorithm Cycle

The Genetic Algorithm cycle used in this study is illustrated in Figure 1.

Start

Random populations of 'n' chromosomes (suitable solutions for the problem) are generated.

Fitness

The fitness function of each chromosome in the population is evaluated.

New Population

A new population is created by repeating following steps.

Selection : Two parent chromosomes are selected from the population according to their fitness, better the fitness, bigger the chance to be selected.

Cross-over : The parents are crossed over to form a new offspring with a cross-over probability.

Childless : If no cross-over is performed, offspring is an exact copy of parents.

Mutation : New offsprings are mutated with a mutation probability.

Accepting : New offsprings are placed in a new population.

Replace : Newly generated population is used for a further run of algorithm, that is, individuals from old population are killed and replaced by the new ones.

Test : The generation is stopped, if the end condition is satisfied and returns the best solution in current population.

Loop : If the termination criteria are not met, the loop is repeated from the fitness step again as reported above.

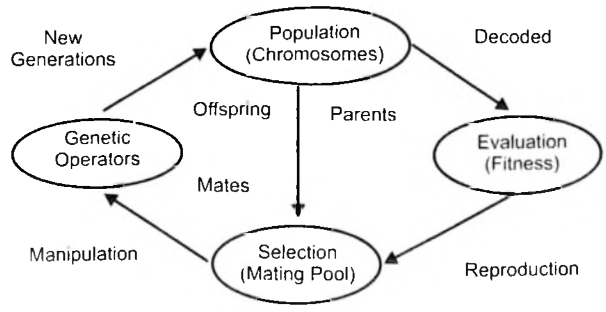

Figure 1 Genetic Algorithm Cycle

OPTIMIZATION PROCEDURE

The FCAW process optimization procedure using genetic algorithm is shown in Figure 2. Here, initial population means the lower bounds of the optimization problems, and each possible solution is called an individual. In this work, a possible solution is formed by values of the welding current (I), welding speed (S), nozzle-to-plate distance (N) and welding gun angle (T) [4].

Fitness Function Evaluation

Fitness function is the objective function that is to minimize. In this study, percentage dilution (D) is taken as objective function [8].

Roulette Selection

This selection function chooses parents for the next generation based on their scaled values from the fitness scaling function. Roulette simulates a roulette wheel with the area of each segment proportional to its expectation. The algorithm then uses a random number to select one of the sections with a probability equal to its area.

Reproduction

Reproduction options determine how the genetic algorithm creates children at each new generation.

Elite count

It specifies the number of individuals that are guaranteed to survive to the next generation. Elite count is a positive integer less than or equal to population size.

Crossover fraction

Crossover fraction specifies the fraction of the next generation, other than elite individuals, that are produced by crossover. The remaining individuals, other than elite individuals, in the next generation are produced by mutation. Crossover fraction to be a fraction between 0 and 1, either by entering the fraction in the text box or moving the slider.

Mutation

Mutation functions make small random changes in the individuals in the population, which provide genetic diversity and enable the GA to search a broader space. In this work uniform function is selected. Uniform is a two-step process. First, the algorithm selects a fraction of the vector entries of an individual for mutation, where each entry has a probability of mutation rate of being mutated. In the second step, the algorithm replaces each selected entry by a random number selected uniformly from the range for that entry.

Cross-over Crossover combines two individuals, or parents, to form a new individual, or child, for the next generation. Intermediate creates children by a weighted average of the parents. Intermediate crossover is controlled by a single parameter Ratio: child1 = parent1 + rand * Ratio * (parent2 - parent1) If Ratio is in the range [0, 1] then the children produced are within the hypercube defined by the parent's locations at opposite vertices.

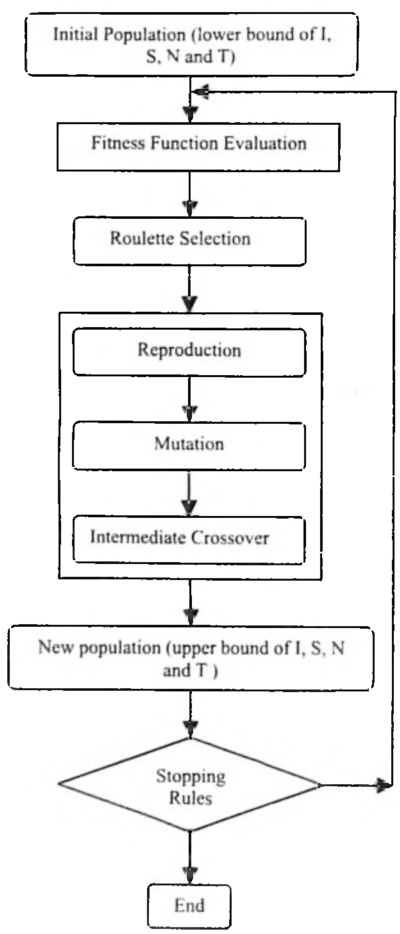

Figure 2 Flowchart for Genetic Algorithm.

If Ratio is in a larger range, say 1.1 then children can be generated outside the hypercube. Ratio can be a scalar or a vector of length Number of variables. If Ratio is a scalar, then all of the children will lie on the line between the parents. If Ratio is a vector then children can be any point within the hypercube.

SIMULATION PROCEDURE

The aim of this study is to find the optimum adjusts for the welding current (I), welding speed (S), nozzle-to-plate distance (N) and welding gun angle (T) in a FCA welding process. The optimum parameters are those who deliver responses the closest possible of the cited values. And it is assumed that the near optimal point is within the following experimental region proposed by Kannan and Murugan [6] and is shown in the Table 1.

Table 1 : GA search ranges

Parameters	Range
Welding current(I)	200-300 A
Welding speed (S)	20-60 cm/min
Nozzle-to-plate distance (N)	22-30 mm
Welding torch angle (T)	0-20°

When the MATLAB command window is opened, M-file has been created and saved as the file name dot m. Then, in the MATLAB command window to open GA tool, type gatool and press enter. When GA toolbox is opened, enter the fitness function as @file name (same file name where the M-file has been saved), number of variables that is used for the fitness function and select the plots required. Following Table 2 show the options used for the study [3, 5, 7].

Table 2 Options of GA computation

Population type	Double Vector
Population size	5
Creation Function	Uniform
Initial range	[-2,-2,-2,-2;2,2,2,2]
Fitness scaling function	Rank
Selection function	Roulette
Reproduction elite count	2
Crossover fraction	0.9
Mutation function	Uniform
Mutation rate	0.01
Crossover function	Intermediate
Migration Direction	Forward
Migration Fraction	0.2
Migration Interval	20
Hybrid Function	none
Number of generations	100
Stall Generations	50
Stall time limit	20

In the GA, the population size, crossover rate and mutation rate are important factors in the performance of the algorithms [3]. A large population size or a higher crossover rate allows exploration of the solution space and reduces the chances of settling for poor solution. However, if they are too large or high, it results in wasted computation time exploring unpromising regions of the solution space.

About mutation rate, if it is too high, there will be much random perturbation, and the offspring will loose the good information of the parents [3]. The 1% value is within the typical range for the mutation rate. The crossover rate is 90%

i.e., 90% of the pairs as crossed, whereas the remaining 10% are added to the next generation without crossover. The chosen type of the crossover was single, which means that a new individual is formed when the parent genes are swapped over at some random single point along their chromosome. Accuracy is the bit quantity for each variable.

RESULTS AND DISCUSSIONS

The mathematical models developed by Kannan and Murugan [1] were used to optimize the process parameters. The procedure is given below.

Selection of objective functions and constraints

The objective function selected for optimization was percentage dilution (D). The response variables bead width (W), penetration (P) and reinforcement (R) were given as constraints in their equation form. In optimization, generally the constraints with their upper bounds should be given in such a way that their value will be less than or equal to zero. Also, the objective function will usually be minimized. To obtain good quality of claddings in any application, it is always desirable to have maximum weld bead width and reinforcement with minimum penetration. The process parameters and their notations used in writing the M-file using MATLAB 7 software are given below.

x(1)=Welding current (I)

x(2)=Welding speed (S)

x(3)=Nozzle-to-plate distance (N)

x(4)=Welding torch angle (T)

Optimization of the function

The main purpose of this paper was using other important clad quality parameters with their limits as constraints. The model is a nonlinear equation with constraints. The constrained minimum of a scalar function of several functions of several variables at an initial estimate, which is referred as "constrained nonlinear optimization" is mathematically stated as follows

Minimize f(x)

Subject to g(x1, x2, x3...xn) <0

The limits of the constraints bead width; penetration and reinforcement were established by data obtained from past experience with a view that they should provide a sound and defect-free clad quality along with a feasible solution to the objective function.

Several numerical methods are available for optimization of non linear equation with constraints. A Genetic Algorithm method is efficient and quickest one, and this method was used to determine the optimum percentage dilution. The step by step procedure of minimization of percentage dilution using the GA optimization tool box available in MATLAB 7 software is given below.

Step 1: writing M-file function [f, g] =f(x)

f(1)=11.702+1.466*x(1)+2.73*x(2)-1.037*x(3)+1.608*x(4)-0.751*x(1)*x(2)-0.593*x(1)*x(3)+1.482*x(2)*x(4); Percentage dilution.

g(1)=27.775+2.494*x(1)-3.244*x(2)+0.45*x(3)-0.61*x(4)-0.303*x(1)^2+1.066*x(2)^2+0.316*x(4)^2-0.616*x(1)*x(2)-39.53; Bead Width and its upper limit.

g(2)=20.15-27.775+2.494*x(1)-3.244*x(2)+0.45*x(3)-0.61*x(4)-0.303*x(1)^2+1.066*x(2)^2+0.316*x(4)^2-0.616*x(1)*x(2); Bead Width and lower limit.

g(3)=0.764+0.104*x(1)+0.074*x(2)-0.048*x(3)+0.11*x(4)+0.021*x(2)^2+0.061*x(2)*x(4)-1.2; Penetration and its upper limit.

g(4)=0.4-0.764+0.104*x(1)+0.074*x(2)-0.048*x(3) +0.11*x(4)+0.021*x(2)^2+0.061*x(2)*x(4); Penetration and its lower limit.

g(5)=4.535+0.128*x(1)-0.475*x(2)+0.054*x(3)+0.052*x(4)+0.053*x(2)^2-0.052*x(2)*x(3)-5.68; Reinforcement and its upper limit.

g(6)=3.63-4.535+0.128*x(1)-0.475*x(2)+0.054*x(3)+0.052*x(4)+0.053*x(2)^2-0.052*x(2)*x(3); Reinforcement and its lower limit.

g(7)=f-20.58; upper limit of percentage dilution.

g(8)=5.31-f; lower limit of percentage dilution.

Step 2: invoke an optimization routine

Select and type the corresponding boxes as per the requirement as shown in the Table 2.

Step 3: Running the M-file.

After running the M-file the optimum values of the process parameters obtained are as follows at 52nd iteration,

x(1)=Welding current (I) = 261.005A

x(2) = Welding speed (S) = 26.28 cm/min

x (3)=Nozzle-to-plate distance (N) = 27.89198 mm

x(4) = Welding torch angle (T) = 11.86535°

For these optimized process parameters, the values of the clad quality parameters are

Bead Width (W) = 36.66542 mm
Penetration (P) = 0.666234 mm
Renforcement (R)= 5.441047 mm
Percentage Dilution (D) = 10.8667%

CONCLUSIONS

The possibility of a FCAW optimization procedure using GA is investigated in this work; more specifically, the determination of the near optimal FCAW process parameters, welding current (I), welding speed (S), nozzle-to-plate distance (N) and welding torch angle (T). The search for the optimization was based on the minimization of an objective function and penetration of the bead.

It was found that GA can be a powerful tool in experimental welding optimization, even when the experimenter does not have a model for the process.

However, the optimization by GA technique requires a good setting of its own parameters, such as population size, number of generations, etc. otherwise there is a risk of an insufficient sweeping of the search space.

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