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ANALYSIS AND OPTIMIZATION OF SAFE WELDING FUMES IN TIG WELDING

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ABSTRACT

The TIG welding processes are accompanied by some toxic aero-disperse particles which can affect the lungs and respiratory system of welders. This paper has developed a near optimal solution to minimize the fume concentration in TIG welding by systematically applying the genetic algorithm approach. A set of individual solutions characterized by genes such as current, voltage and gas flow rate has been considered. Optimal solution was achieved by population, selection, rossover and mutation procedures. The iteration was performed over 450 generations and 100 stall generations with function and constraint tolerances of 1e-06 and 1e-04 respectively. The genealogy, selection and rank histogram shows the parents contributing to each generation. The pareto optimal solution was obtained and the 10th individual was selected as the fittest. With a current of 170.20 amps, voltage of 19 volts and gas flow rate of 11.31 lit/min will produce a weld with minimum fume concentration of 2.99. The Genetic Algorithm optimal solution can help fabrication experts to reduce the hazards exposed to welders and improve their health integrity.

KEYWORDS: Fumes, Optimization, Genetic Algorithm, Tungsten Inert Gas, Welding, Mutation.

1. INTRODUCTION

Welding technology is a very important manufacturing process employed in the maintenance of marine and offshore structures, and is also applied in metal work construction. Today, most of the welding operations are done with the aid of automation and robotics systems. Producing welds manually has a lot of challenges such as generation of fumes, which impacts on the welders health negatively.[1] welding process release fumes that consist of powders of different solid substances like Cu, Ni and Zn.With sizes ranging from 1 to 7 µm. The fumes contain gases such as CO_2, CO, NO_2, SO_2, O_3, etc., and numerous organic contaminants are also produced during the welding process. The fumes are generated and emitted due to the presence of excessive heat, ultraviolet radiation arising from the arc, and reactions of hot base metal with atmospheric O_2 and N_2.[2] Welders inhaling these fumes can be exposed to danger as these gases have a great effect on lung function and causes severe acute respiratory disease as well as chronic diseases like lung cancer,. Hence, it is very essential to protect workers from welding fume exposure. Reduction of welding fumes from workers zone is generally achieved by three processes: reduction at the source by changes in process and conditions, use of ventilation and exhausts, and use of a device for personal protection.[3] The density, size and shape of welding fumes have a strong influence on the biological activity of the welding fume. Therefore, investigating and understanding the relationship between the welding fume Particle size distribution (PSD) and the arc welding parameters are of great importance.[4] Based on numerical methods, research has been done for prediction of particle concentration using Computational Fluid Dynamics (CFD) but the simulated results frequently have some divergence from the experimental results.[5] Fume generated by the shielded metal arc welding (SMAW) process may be a cause for concern due to possible health problems experienced by individuals in the welding industry after long-term exposure. Welding fume particles may cause metal fume fever, and perhaps more importantly, manganese- or chromium related poisoning after inhalation and ingestion into the human body. For example, it has been proposed that long term, low concentration doses of Mn are linked to nervous system disorders.[6] Studies have also shown that welders working with stainless steels who have had cases of lung cancer may be due to possible hexavalent chromium exposure, although there has been no direct evidence linking the cancer to welding fume exposure.[7] Occupational exposure limits (OEL), which are revised quite regularly, determine the amount of these compounds and elements that may be ingested without becoming harmful to human tissues. Though epidemiological reactions to the different compounds present in welding fume are important, they are beyond the scope of this study, which was designed to characterize the fume particles produced by metal joining processes.[8]

Aerosol consisting of fume and spatter is produced during welding with SMAW electrodes. Previous studies have shown that SMAW fume consists of an assortment of metals, oxides, and other compounds, which form from evaporation of elements in the arc and fluxes covering the electrode.[9] Fume particles generally vary over a wide range of sizes, thus it becomes important to consider fume particles in each size range as opposed to bulk composition alone. Interactions between particle size and composition have also been found. Number and mass distributions of welding fumes have been measured with a variety of techniques including cascade impactors, scanning mobility particle sizers, and optical particle counters. These distributions have typically shown that fume particles are present in a broad range of sizes but are generally present in higher concentrations of small particle sizes and higher masses of the larger particle sizes. Fume formation is of great interest in order to understand the varying morphologies and compositions of bulk fume.[10]

2. Research Methodology

2.1 Design of Experiment

To develop optimal solutions an accurate experimental design is very necessary for data collection. Design of experiment is a an expert method of combining process parameters optimally using scientific methods, this is determined by the number of input parameters considered. The experimental design considers the following factors such as welding current, gas flow rate, and voltage as input. In this study the experimental matrix was developed using the design expert software, the central composite design was the most suitable for this experiment. The input factors considered and their levels is shown in the table below.

Table 2.1: determination of range of input process parameters.

Parameters	**Unit**	**Symbol**	**Coded value**	**Coded value**
			Low(-1)	High(+1)
Current	Amp	A	150	180
Gas flow rate	Lit/min	F	36	42
Voltage	Volt	V	10	13

Table 2.2: Experimental data.

Current	Voltage	Gas flow	Fume concentration	Electrode melting rate	Melting temperature	Heat transfer coefficient
165.00	17.50	11.50	5	8	1441	279
165.00	17.50	14.02	29	25	1644	200
150.00	19.00	13.00	20	13	1615	219
165.00	17.50	11.50	3.5	6	1449	279
165.00	17.50	11.50	2	4	1473	280
165.00	20.02	11.50	1.6	2	1205	263.67
180.00	16.00	10.00	1.08	7	1369.6	234.05
139.77	17.50	11.50	11	24	1673.2	253.74
165.00	17.50	11.50	2	5	1452	268.1
165.00	14.98	11.50	1.2	0.8	1280	233.12
190.23	17.50	11.50	1.1	19	1488	248.24
150.00	19.00	10.00	4	3	1520	253.74
150.00	16.00	10.00	6	7	1392.5	215.2
180.00	19.00	10.00	4	4	1398.7	254.6
165.00	17.50	11.50	1.8	4.7	1395.1	263.67
165.00	17.50	11.50	1.5	4.25	1484.4	280
165.00	17.50	8.98	10	4	1540.8	240
150.00	16.00	13.00	11	14	1529.3	222
180.00	19.00	13.00	15	22	1400.2	200
180.00	16.00	13.00	2	9	1474.9	220

2.2. Experimental procedure

The mild steel plates are cut into coupons with the aid of a Power Hacksaw. The mild steel samples were grinded, sand cleaned and etched to get a fine edge because sample has to be free from grease and dirt. 100 pieces of mild steel coupons was produced for this experiment which was joined together with the aid of the gas tungsten arc welding process using 100% argon gas as the shielding gas and a direct current Electrode positive (reverse polarity) was used. In this process the tungsten non consumable electrode having diameter 3 mm was used alongside a 2 mm diameter filler metal ER309L was used for the welding. Thereafter the fume concentration, electrode melting rate, electrode melting temperature and heat transfer coefficient were determined and recorded respectively.

2.3. Materials used for the experiment

Low carbon steel popularly known as Mild Steel is one of the most common of all metals used in the fabrication projects.

The choice of mild steel was made because of its affordability, availability, durability, having less than 2 % carbon, gives it a high magnetic quality which supports the weldability of mild steel.

Figure 2.1: welded torch.

Figure 2.2: TIG shielding gas cylinder.

Figure 2.3: welded samples.

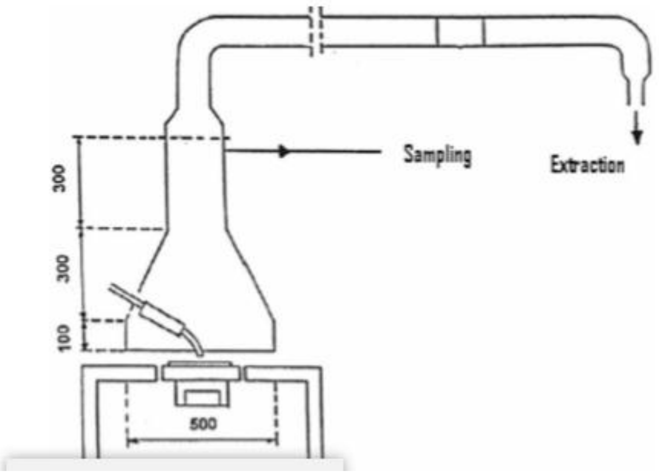

Figure 2.4: Fume collection setup.

3 RESULTS AND DISCUSSION

3.1 Genetic Algorithm Optimization

The genetic algorithm is applied in this study to search for near optimal solution that will best minimize welding fume concentration in TIG weldingThe first step taken for the GA approach is to develop a fitness function.Equations 1 to 4 are the fitness function equation for the above problem.

$$f_1 = [125.42 - 0.53x_1 - 1.93x_2 - 11.213x_3 + 0.015x_1x_2 - 0.0061x_1x_3 + 0.17x_2x_3 + 0.00091{x_1}^2 - 0.067{x_2}^2 + 0.42{x_3}^2]^2 \quad (1)$$

$$f_2 = [126.24 - 1.38x_1 + 2.83x_2 - 6.63x_3 + 0.012x_1x_2 + 0.00042x_1x_3 + 0.173x_2x_3 + 0.00355{x_1}^2 - 0.19{x_2}^2 + 0.177{x_3}^2]^2 \quad (2)$$

$$f_3 = [-81.99 - 0.46x_1 + 20.11x_2 - 2.78x_3 - 0.0186x_1x_2 - 0.0087x_1x_3 - 0.109x_2x_3 + 0.0026{x_1}^2 - 0.45{x_2}^2 + 0.28{x_3}^2]^2 \quad (3)$$

$$f_4 = [-176.93 - 0.69x_1 + 8.62x_2 + 10.73x_3 + 0.0066x_1x_2 - 0.0077x_1x_3 - 0.15x_2x_3 - 0.0015{x_1}^2 - 0.016{x_2}^2 + 0.31{x_3}^2]^2 \quad (4)$$

Where x_1 = current, x_2 = voltage, $x_{3=,}$ gas flow rate

Where F_1 =fume concentration,F_2 = electrode melting rate,$F_{3=,}$ electrode melting temperature, $F_{4=}$ heat transfer coefficient. We are to minimize F.

3.2 Initial Population

The population is a makeup of set of individuals characterized by a set of parameters which are fume concentration, electrode melting rate, melting temperature and heat transfer coefficient while the genes in this study are input variables such as the current, voltage gas flow rate. Using Matlab 2015 optimization toolbox, a population type of “double vector” and “population size” 50 was generated using “constraint dependent” creation function. A “tournament selection” function with a tournament size of 4 was used to randomly choose the individuals with high fitness values to produce offspring with even higher fitness. A 0.8 crossover fraction was used to create children at each new generation. An “adaptive feasible” mutation function was used to make small random changes in the individuals in the population, which provided genetic diversity and enable the genetic algorithm to search a broader space. Using “constraint dependent” crossover function, two individuals, or parents were combined to form a new individual, or child, for the next generation. With a forward direction migration function, a migration fraction of 0.2 and an interval of 20, the best individuals from one subpopulation was used to replace the worst individuals in another sub population. The iteration was performed over 450 generations and 100 stall generations with function and constraint tolerances of 1e-06 and 1e-04 respectivelyThe population is as shown in table 3.1.

Table 3.1: Genetic Algorithm Population Table.

	Current	voltage	Gas flow rate
1	167.490	16.000	8.980
2	167.490	16.000	8.980
3	167.490	16.000	8.980
4	168.664	18.997	13.000
5	167.491	17.711	8.984
6	170.210	16.000	11.301
7	168.889	18.933	11.407
8	167.491	19.000	9.244
9	168.716	18.911	10.793
10	170.210	16.000	11.297

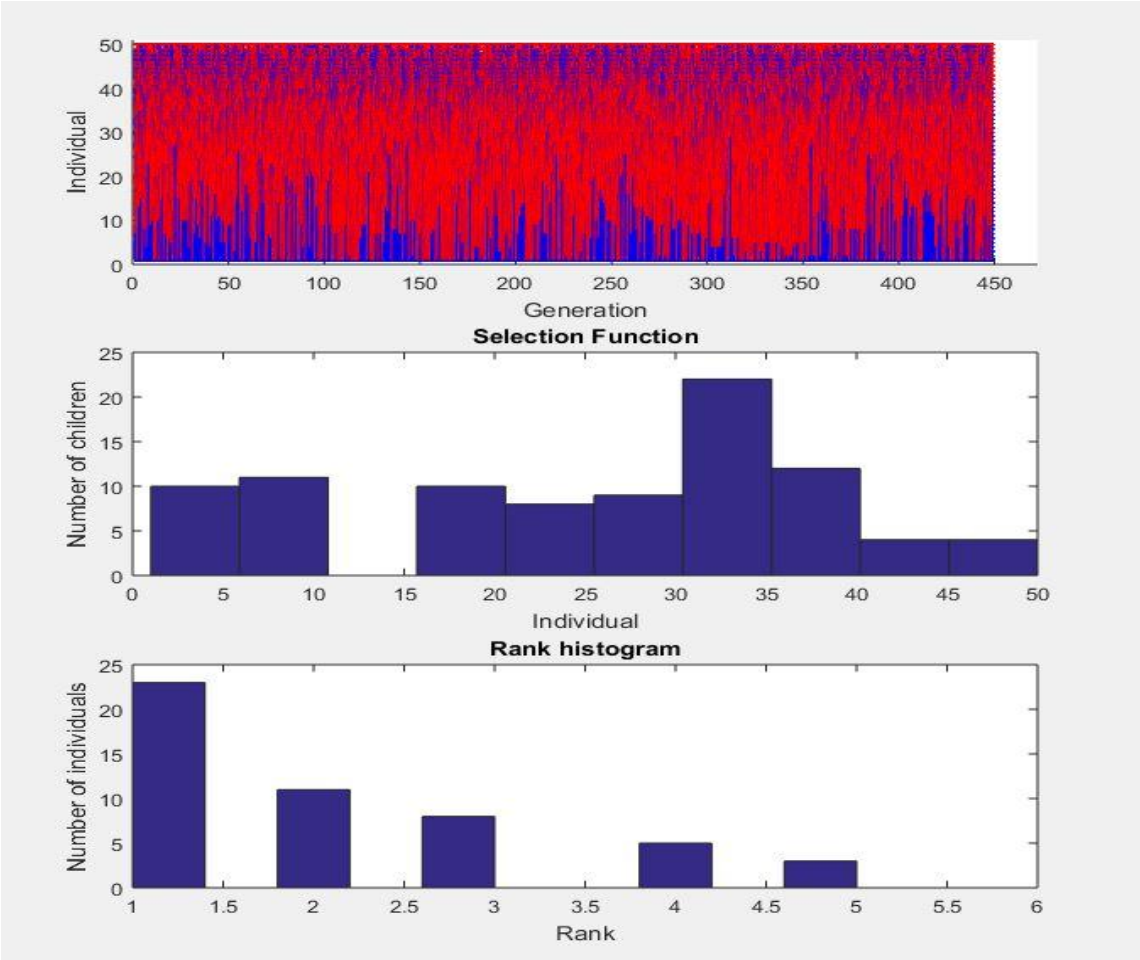

Figure 3.1 Genealogy, Selection and Rank histogram.

Figure 3.1 shows the genealogy, the selection function and the rank histogram plots of the genetic algorithm. Red colored lines in the genealogy plot indicate mutation children, blue lines indicate crossover children and black lines indicate elite individuals. Selection plots a histogram of the parents and shows which parents are contributing to each generation. Rank histogram plots the fraction of individuals in each Pareto tier. Rank 1 individuals are best, rank 2 individuals are dominated only by rank 1 individuals and so on.

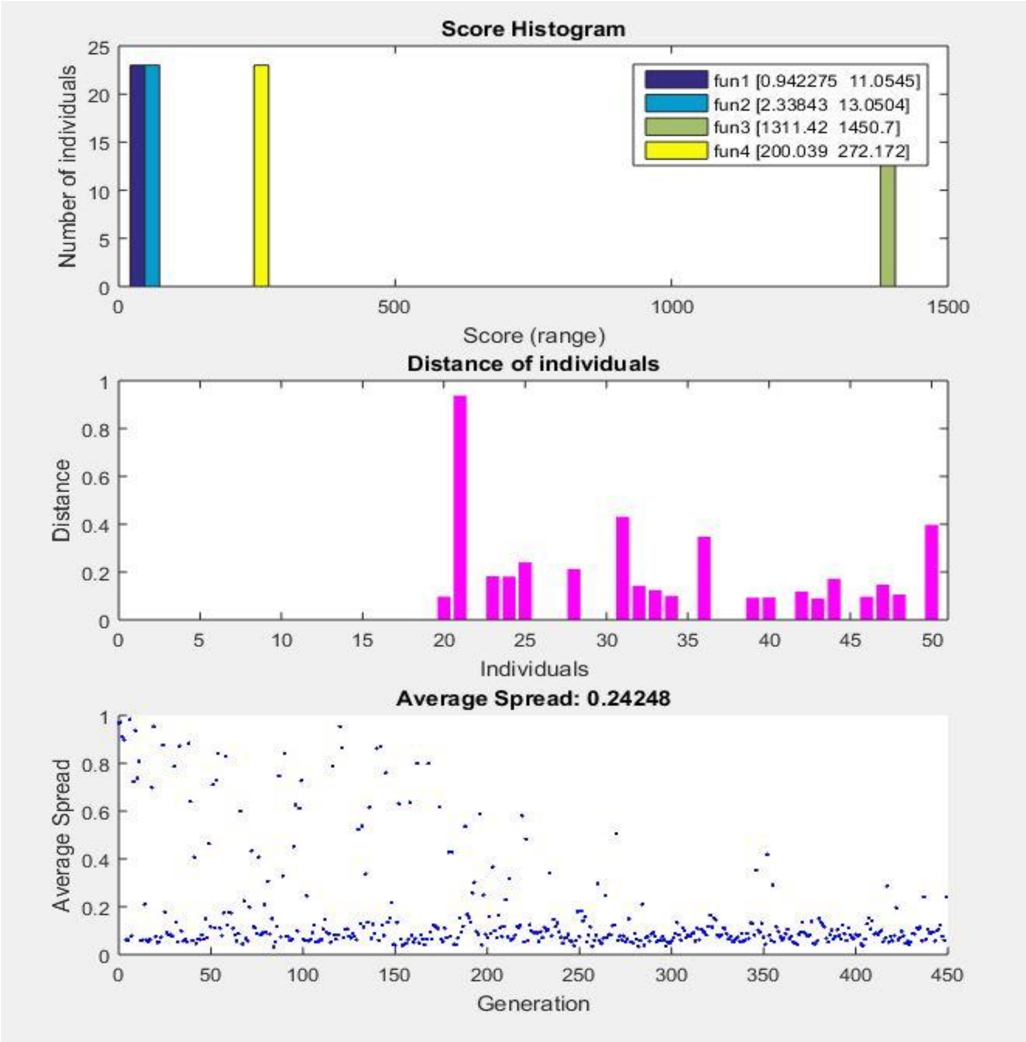

Figure 3.2: Score histogram, Average Distance and Average Spread.

Figure 3.2 shows the score histogram, average Pareto distance and the average Pareto spread. The score diversity plots a histogram of the scores at each generation. Average Pareto spread is a plot of the change in distance measure of individuals with respect to the previous generation. Average Pareto distance plots the average distance measure between individuals. A set of optimal solutions was obtained based on the pareto distance is shown in table 3.2.

Table 3.2: Pareto Optimal Solutions

	x1	x2	x3	f1	f2	f3	f4
1	167.4900	16.0000	8.9800	11.0545	5.3422	1387.4454	200.0391
2	167.4906	19.0000	9.2444	5.7931	2.3384	1407.5060	252.2367
3	170.2100	16.0001	11.2970	0.9423	3.3796	1335.1754	253.8338
4	169.2041	18.9951	11.8200	4.4722	7.6086	1321.1000	257.6467
5	170.1848	18.9940	12.1408	6.0351	9.6682	1325.9993	248.2643
6	170.1437	18.9975	11.7183	4.0565	7.3160	1315.2062	259.0488
7	167.4907	18.7593	9.0614	7.4259	2.9573	1443.0878	246.5666
8	167.4901	16.0000	8.9800	11.0544	5.3422	1387.4455	200.0391
9	169.4706	18.9911	12.0295	5.4361	8.8114	1325.7423	252.1625
10	**170.2099**	**19.0000**	**11.3172**	**2.9978**	**5.6823**	**1311.4220**	**266.0828**

4. CONCLUSION

In this paper a near optimal solution for minimizing welding fume concentration in TIG welding process has been achieved. A genetic algorithm approach has been systematically applied using the MAT lab software considering a set of individual solutions characterized by genes such as current, voltage and gas flow rate. The global optimal solution was obtained by taking the following steps of population, selection, crossover, mutation and termination. The iteration was performed over 450 generations and 100 stall generations with function and constraint tolerances of 1e-06 and 1e-04 respectively. Figure 3.1 shows the genealogy, selection and rank histogram which shows the parents contributing to each generation The pareto optimal solution was obtained and the 10th individual was selected as the fittest. a current of 170.20 amp, voltage of 19 volts and gas flow rate of 11.31 lit/min will produce a weld with minimum fume concentration of 2.99. application of the Genetic Algorithm optimal solution can help to reduce the hazards exposed to welders and improve their health integrity.

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