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A Fuzzy Logic Approach to Predict Tensile Strength in TIG Mild Steel Welds

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Abstract

Welding defects influence the desired properties of welded joints giving fabrication experts a common problem of not being able to produce weld structures with optimal strength and quality. In this study, the fuzzy logic system was employed to predict welding tensile strength. 30 sets of welding experiments were conducted and tensile strength data was collected which were converted from crisp variables into fuzzy sets. The result showed that the fuzzy logic tool is a highly effective tool for predicting tensile strength present in TIG mild steel weld having a coefficient of determination value of 99%.

Keywords

Tensile Strength, Predict, Steel, Fuzzy Logic, Tungsten Inert Gas, Welding

1. Introduction

Manual metal arc welding was first invented in Russia in 1888 [1].

It involved a bare metal rod with no flux coating to give a protective gas shield. Welding was defined as an efficient and economical method for joining of metals. Welding has made significant impact on the large number of industry by raising their operational efficiency, productivity and service life the plant and relevant equipment [2].

Welding is one of the most common fabrication techniques which is extensively used to obtain good quality weld joints for various structural components. Welding is a joining process that involves intensive heating of the weldments, which causes an uneven temperature distribution and consequently local plastic strain in the weld and surrounding metal [3].

The mismatch of the plastic strains between the weld and the parent metal causes compressive stress, which can have adverse effects on the mechanical properties. Welding in steel structures design happens to be most the widely employed joining technology and it is well known to suffer challenges of corrosion and fatigue. Welding defects influence the desired properties of welded joints giving Fabrication experts a common problem of not being able to produce weld structures with optimal strength and quality. The reason TIG is becoming the most preferred technology is that it has the cleanest weld bead [4].

TIG welding is done in a controlled atmosphere using a tungsten electrode which serves to produce an arc to melt the metal. Direct current (DC) or Alternating Current of High Frequency (ACHF) is used to enable the resulting continuous and stable arc without touching the metal electrode.

The use of artificial intelligence to analyze welding parameters and develop mathematical models produces contour plots relating important input parameters such as penetration size and reinforcement height of the weld bead highlighted [5]. Several techniques connected to neural networks were explained and how they can be used to model TIG weld output parameters, the experimental data consisted of values for voltage, current, welding speed and wire feed speed and the corresponding bead width, penetration, reinforcement height and bead cross-sectional area [6].

The performance of Fuzzy Logic for weld modeling was presented and evaluated using actual welding data. It was concluded that the accuracy of neural networks modelling is fully comparable with the accuracy achieved by more traditional modelling schemes [7].

The application of artificial intelligence concepts such as Fuzzy Logic model predicts the mechanical properties of steels. It was found that the three FL model successfully predicted the mechanical properties. It was also shown that FL could successfully predict multiple mechanical properties and the results of the sensitivity analysis were in agreement with both findings of the experimental investigation and reported results in the literature [8].

FL model was developed for the analysis and simulation of the correlation between friction stir welding (FSW) parameters of aluminum plates and mechanical properties of the welded joint. The process parameters consist of weld speed and tool rotation speed verses the output mechanical properties of weld joint, namely: tensile strength, yield strength, elongation good performance of the FL model was achieved and the model can be used to calculate mechanical properties of the welded plates [9].

The use of FL resulted in large economic benefits for organizations through minimizing the need for expensive experimental investigation and/or inspection of steels used in various applications. It will help in the area of quality control and assist industries that depend on welded materials for their operations.

2. Research Methodology

2.1. Design of Experiment

Design of experiment is a very important step taken to accurately apply artificial intelligent methods to either minimize or maximize a targeted manufacturing response. The experimental design considers the following factors such as welding current, gas flow rate, and voltage as input. The experimental matrix was generated with the design expert software, the central composite design was the most suitable for this experiment. This process followed the rules of repetition, randomization and local control so as to achieve an optimal experimental design. The input factors considered and their levels are shown in the tables below (Table 1, Table 2).

Table 1. Process factors and their range.

Parameters	Unit	Symbol	Coded value	Coded value
			Low (−1)	High (+1)
Current	Amp	A	180	240
Gas flow rate	Lit/min	F	18	24
Voltage	Volt	V	16	22

Table 2. Experimental results of Tensile Strength.

Run	Type	Current (A)	Voltage (V)	Gas flow rate (Lit/min)	Tensile Strength (Mpa)
1	Center	200	42	7	460.3
2	Center	200	42	7	430.5
3	Center	200	42	7	456.7
4	Center	200	42	7	440.3
5	Center	200	42	7	430.8
6	Center	200	42	7	460.5
7	Fact	180	36	4	360.8
8	Fact	220	36	4	450.3
9	Fact	180	48	4	460.7
10	Fact	220	48	4	470.8
11	Fact	180	36	10	320.4
12	Fact	220	36	10	480.9
13	Fact	180	48	10	380.9
14	Fact	220	48	10	477.5
15	Axial	166.4	42	7	321.4
16	Axial	233.6	42	7	475.6
17	Axial	200	31.9	7	405.8
18	Axial	200	52.1	7	480.9
19	Axial	200	42	1.9	464.9
20	Axial	200	42	12.0	450.6

2.2. Experimental Procedure

Power Hacksaw was used for cutting the mild steel plate to size measuring 60 × 40 × 10 mm. The grinding machine was used for preparing the groove on the double transverse side of the plates of Mild Steel Subsequently single "V" groove angles (30 degree) were cut in the plates with 2 mm root faces for a total of 60 degree inclined angle between after the V-groove preparation, the Mild Steel were ready for the welding. The mild steel plates were tightly clamped during welding.

The root gap of 2 mm is provided between the two plates while performed for the welding. The V-groove butt welding is performed during TIG welding process. The tungsten non consumable electrode having diameter 3 mm was used in experiment. The argon gas is used as a shielding gas. The pressure regulator was used to adjust the gas flow rate during operation. The filler metal ER309L having 2 mm diameter was used for the welding. The direct current Electrode positive (reverse polarity) was used for the welding (**Figures 1-3**).

Figure 1. Weld samples.

Figure 2. TIG shielding gas cylinder.

Figure 3. TIG equipment.

2.3. Materials Used for the Experiment

Mild Steel is one of the most common of all metals and one of the least expensive steels used. It is found in almost every product created from metal. It is easily weld able, very durable. Having less than 2% carbon, it will magnetize well and being relatively inexpensive can be used in most projects requiring a lot of steel.

3. Results and Discussion

3.1. Defining the Linguistic Variables and Terms

Consider a fuzzy logic model aimed at predicting fatigue. Let the weld factors, namely; current (c), voltage (v) and gas flow rate (gfr) be termed the linguistic variables. To qualify the current, voltage and gas flow rate, terms such as (very low, low, moderate, high and very high) are used in real life. These are the linguistic values of the current, voltage and gas flow rate. Therefore, C (c) = {very-low, low, moderate, high and very high} V (v) = {very low, low, moderate, high and very high} GFR (gfr) = {very low, low, moderate, high and very high}In the same way, the output variable (fatigue) can be qualified in real term as: (FG) = {very low, low, moderate, high and very high}.The terms in bracket represent the set of decompositions for the linguistic variable current, voltage, gas flow rate and fatigue. Each member of this decomposition is called a linguistic term. For this problem, the linguistic variables and their range of values include:

- Current; this range from 180 to 220 amps;
- Voltage; this range from 36 to 48 volts;
- Gas flow rate; this range from 4 to 10 L/min;
- Tensile; this range from 320.40 to 480.90 Mpa.

The fuzzy logic tool box that defines the input and output variables is presented in Figure 4.

3.2. Converting the Crisp Variables into Fuzzy Sets

To convert the crisp variables (actual experimental data) into fuzzy sets, adaptive neuro fuzzy inference system (Anfis) was employed to generate a fuzzy inference system (FIS). For this problem, the fuzzifiation step was done using anfis as presented in Figure 5.

Membership functions are used in the fuzzification and defuzzification steps of a Fuzzy Logic Systems (FLS), to map the non-fuzzy inputvalues to fuzzy linguistic terms and vice versa. A membership function is used in most cases to quantify a linguistic term.

3.3. Definition of Membership Function for Current

Figure 6 shows the definition of the membership function for current.

Figure 6 shows the membership function for current. The current range is specified as [166.4 233.6] while the membership set that defines low current is given as [149.5 166.4 183.2]. The membership function type is the triangular membership function.

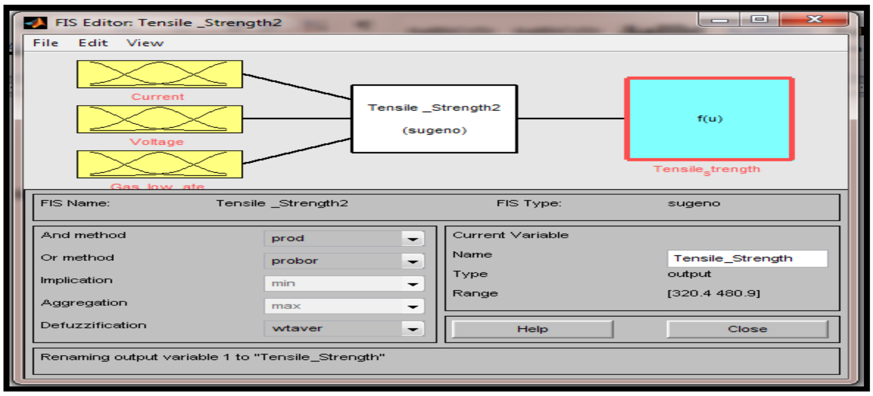

Figure 4. Fuzzy logic tool box containing the input and output variables.

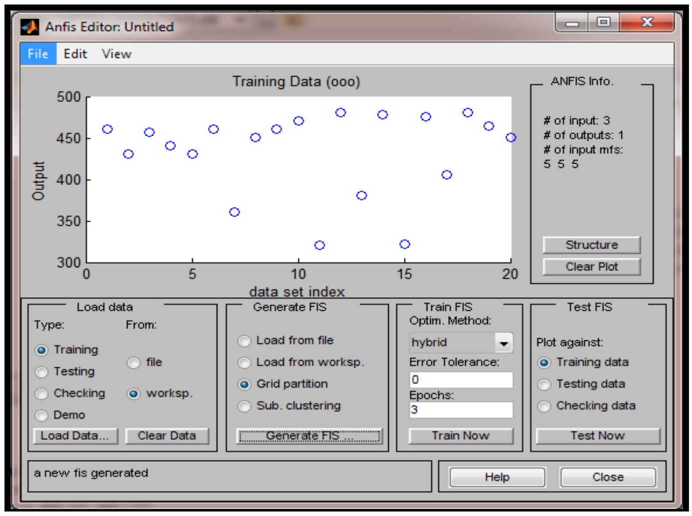

Figure 5. Defining the inputs and output membership function.

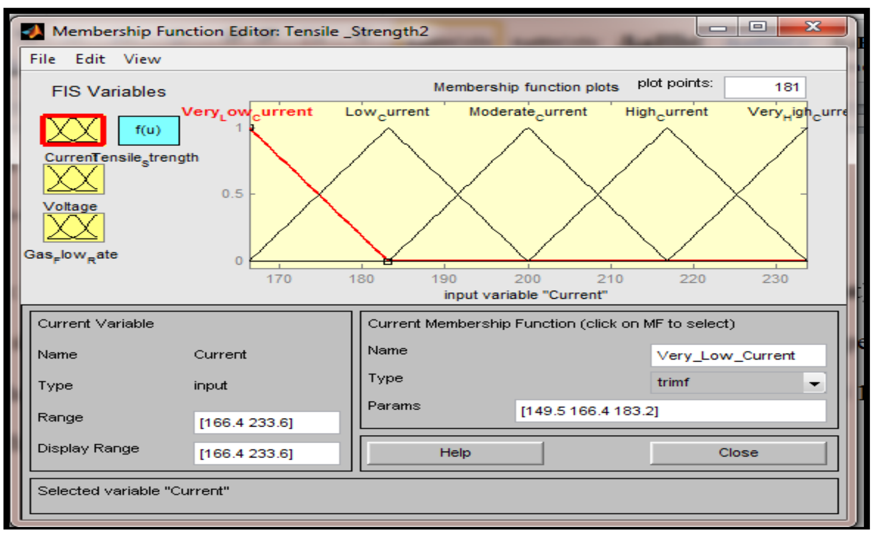

Figure 6. Definition of membership function for current (low current).

3.4. Definition of Membership Function for Voltage

Figure 7 shows the definition of the membership function for voltage.

Figure 7 shows the membership function for voltage. The voltage range is specified as [31.91 52.09] while the membership set that defines very low voltage is given as [26.86 31.91 36.95]. The membership function type is the triangular membership function.

3.5. Definition of Membership Function for Tensile Strength

Figure 8 show the definition of the membership function for Tensile strength.

Figure 8 shows the membership function for tensile strength. The range for tensile strength is specified as [320.3 480.9] while the membership set that defines << very low tensile strength is given as 320.4. The membership function type is the constant membership function.

3.6. Predicting Tensile Strength Using Fuzzy Logic

Figure 9 show the predictions that were made using fuzzy logic systems.

From the result of Figure 9, it was observed that; for a current of 200 Amp, voltage of 42 volt, and gas flow rate of 7.0 L/min, the predicted tensile strength was 447 Mpa. A comparison between the experimental and the fuzzy logic predicted results for tensile strength response is presented in Table 3.

Table 3. Experimental and fuzzy logic predicted results for tensile strength.

Run No.	Current (A)	Voltage (V)	Gas Flow Rate (L/min)	Tensile Strength (Mpa) Experimental Values	Tensile Strength (Mpa) FL Predicted Values
1	200	42	7	460.3	447
2	200	42	7	430.5	447
3	200	42	7	456.7	447
4	200	42	7	440.3	447
5	200	42	7	430.8	447
6	200	42	7	460.5	447
7	180	36	4	360.8	361
8	220	36	4	450.3	450
9	180	48	4	460.7	461
10	220	48	4	470.8	471
11	180	36	10	320.4	320
12	220	36	10	480.9	481
13	180	48	10	380.9	381
14	220	48	10	477.5	478
15	166.4	42	7	321.4	321
16	233.6	42	7	475.6	476
17	200	31.9	7	405.8	406
18	200	52.1	7	480.9	480
19	200	42	1.9	464.9	465
20	200	42	12.0	450.6	450

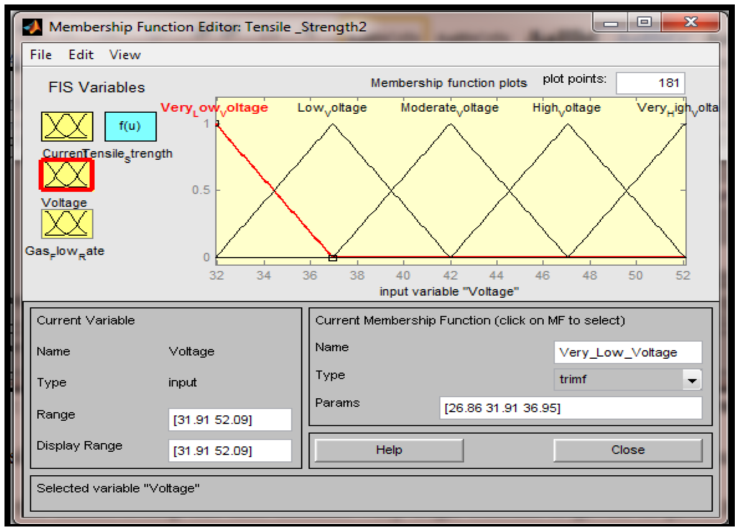

Figure 7. Definition of membership function for voltage (very low voltage).

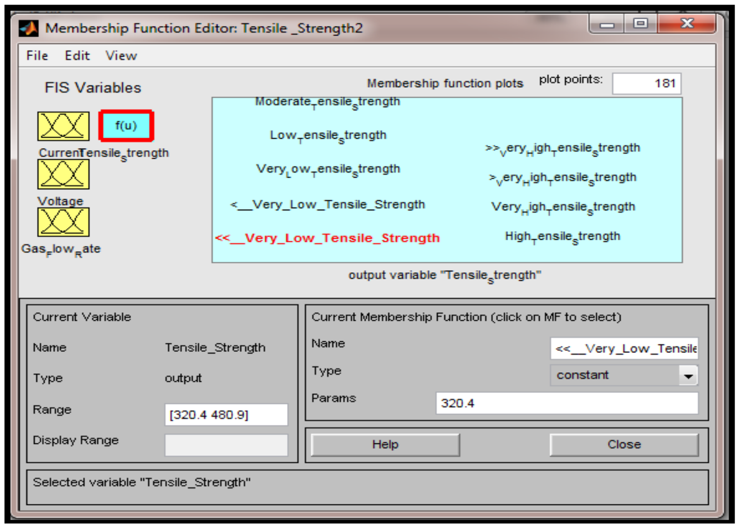

Figure 8. Definition of membership function for tensile strength.

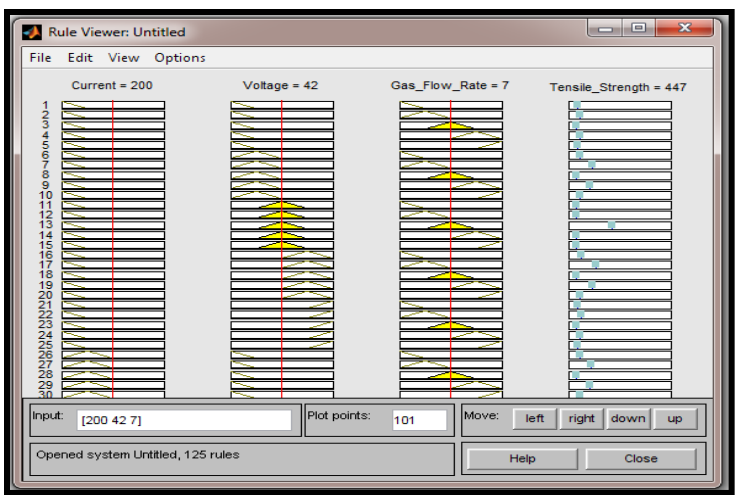

Figure 9. Prediction of tensile strength using fuzzy logic.

4. Conclusion

In this paper the tensile strength response of TIG welding process has been predicted so as to obtain the welding parameters of the weldments. This study has systematically applied the fuzzy logic to predict tensile strength of Tungsten inert gas mild steel weld. The results obtained show that the tensile strength of TIG mild steel weld is strongly influenced by input variables such as current, voltage and gas flow rate. The result obtained from the fuzzy logic system showed that the fuzzy logic tool is a highly effective tool for predicting tensile strength in TIG having a coefficient of determination value of 99%. The result shows that a current of 200 amp, voltage of 42 volt, and gas flow rate of 7 L/min will result in a welding process with tensile strength of 447.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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