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Prediction of convective heat loss on surface of weld during TIG welding using an adaptive Neuro-Fuzzy Inference System ANFIS

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Abstract

Using the ANFIS, this study investigates the prediction of convective heat loss on the weld surface during TIG welding. Welding current, welding voltage, and welding speed are the employed process parameters in this investigation. Using 100 pieces of 80 x 40 x 10 mm mild steel coupons was the experiment's requirement. With argon serving as the shielding gas, the experiment was carried out 20 times, utilizing 5 specimens per run. For uniting the weld materials, a tungsten inert gas machine was used. Using the data from the experimental technique, the convective heat loss on the weldment surface was then calculated. From the given input values, ANFIS was utilized to forecast the convective heat loss on the weld surface. An intelligent model was developed to predict the welding parameters and their effect on convective heat loss on the weld surface. The convective heat loss on the weld's surface was predicted using ANFIS. The estimated convection heat loss for a 180 amp current, 2.8 mm/s welding speed, and 21 volts applied to the weld surface was 0.405 (W/m2K). According to the results, the model can optimize convective heat loss on the weld surface by 92.68%.

Keywords: TIG, convective, heat loss, ANFIS, Shielding gas

1. Introduction

Welding is the most widely used connection technique, especially when working with metals. Depending on the design need, it offers several advantages over other methods like as using bolts, nuts, and rivets. Shielded metal arc welding (SMAW), gas metal arc welding (GMAW), plasma arc welding (PAW), and gas tungsten arc welding (GTAW), often known as tungsten inert gas (TIG) welding, are among the various types of metal welding techniques [1] One well-known conventional Arc welding method is tungsten inert gas (TIG) welding. This method is used because it can transfer heat locally to the welding line and has strong, controlled qualities [2]. In TIG arc welding, a non-consumable tungsten electrode is used to create an arc on the workpiece. This welding method was applied to the metals utilizing an inert gas shielding pool. The TIG welding method is a dependable welding technology that yields high-quality welds, based on past experiences. Fumes and leaks are not common during this operation [3]. This technique is used to create various steel items for lower cost and greater quality welds [4]. It has been determined that during the arc welding process, an electric arc transfers energy from the welding electrode to the base metal. Enough power (energy transmitted per unit of time) and energy density are applied to the electrode to initiate the arc. As a result, to generate the weld, the base metal and the filler metal are both heated [4]. The goal of this research is to use ANFIS to optimize and anticipate convective heat loss on the weld surface during TIG welding under steady state conditions. The drive comes from the need to understand why structural breakdowns and defects have occurred in the fabrication industries over time, as well as the necessity to help propose remedies by identifying the ideal parameters and combinations that would prevent less-than-ideal fabrication processes. Throughout the welding process, numerous flaws appeared [5].

Welding defects: What is it? The imperfections created in the supplied weld metal as a result of improper welding process settings, improper welding patterns, etc. are referred to as welding defects. The shape, size, and intended quality of the weld bead may not match the fault [5]. There could be welding flaws on the outside or inside of the weldment. Certain defects, such cracks, porosity, inappropriate penetration, etc., are never acceptable; nevertheless, other defects might be approved if they fall within acceptable bounds [5]. Reda *et al*. applied thermal, mechanical, and metallurgical finite element methods (FEM) analysis during TIG welding. Numerous researchers have worked on various welding-related topics. By monitoring temperature, weld bead diameters, and residual stresses, they used experimental methods to validate their computer model. They stood for the ideal welding current range [6]. Shiva Naga *et al*. calculated welding strength in 2020 using a variety of input factors, including voltage, current, and weld speed. They determined the ideal welding speed, current, and voltage for Al 7068 in order to maximize the tensile strength [7]. Using response surface approach, Eboigbe and Ikponmwosa-Eweka are among the researchers who have utilized the TIG welding procedure in their research. They have also optimized the residual stress in mild steel gas tungsten arc welded joints [8].

2. Materials and Methods

Mild steel plate was used for the test piece, and a power hack saw was used to cut it into pieces. The samples were edge-machined, cleaned, ground, and longitudinally cut. Using tungsten inert gas welding equipment, the weld specimen was produced after the edges were machined. In order to produce the 100 weldment samples that were used in the research, 200 mild steel coupons measuring 80 x 40 x 10 mm were used. Twenty runs of the experiment were conducted, using five specimens each. Twenty experimental runs were produced by creating the center composite design matrix with the help of the design expert program. The experimental design process was aided by the use of Expert Design version 7.01. The input parameters (Current I, voltage V, welding speed M/s) and output parameters (Convective Heat Loss on Surface of Weld) make up the experimental matrix. The answers recorded from the weld samples served as the data source for the matrix. 100% pure argon gas was used as a shielding gas in this research study. The parameters employed and their various levels are shown in Table 1 and it was extracted from existing research work.

Table 1: Process parameters and their levels

Parameters Entered	Unit	Symbol	Low (-)	High (+)
Current	Amp	I	170	190
Voltage	Volts	V	20	22
Speed	Mm/Sec	M	2.6	3.0

3. Results and Discussion

The experiment's outcomes, which were correctly documented and identified as experimental results, are shown in Table 2.

Table 2: Experimental results

S/N	Input Parameters					
	Current I, Amp	Speed mm/sec	Voltage, Volts	To °C	T_L °C	Convective Heat loss on Surface of the weld, (W/m^{2}K)
1	190	2.63	20.73	35	1610	0.35
2	190	2.63	20.72	32	1592	0.26
3	190	2.63	20.70	33	1598	0.38
4	190	2.63	20.68	29	1625	0.46
5	190	2.62	20.78	36	1720	0.40
6	170	2.80	20.00	35	1672	0.33
7	170	3.00	21.00	34	1658	0.39
8	170	3.00	22.00	36	1586	0.47
9	170	3.00	20.00	38	1615	0.41
10	180	2.60	21.00	30	1710	0.37
11	180	2.60	22.00	35	1672	0.19
12	180	2.60	20.00	31	1545	0.32
13	180	2.80	21.00	37	1640	0.43
14	180	2.80	22.00	36	1655	0.50
15	180	2.80	20.00	38	1632	0.41
16	180	3.00	21.00	32	1610	0.41
17	180	3.00	22.00	37	1698	0.43
18	180	3.00	20.00	36	1668	0.41
19	190	2.60	21.00	34	1628	0.41
20	190	2.60	22.00	32	1646	0.41

3.1. Adaptive Neuro-fuzzy Inference System for Convective Heat Loss Prediction on Weld Surface: Defining Terminologies and Linguistic Variables

Instead of having numerical numbers as their values, linguistic variables are the system's input or output variables that take the form of words or sentences from natural languages. The general breakdown of a linguistic variable is into a collection of linguistic terms. Think about a welding procedure designed to anticipate convective heat loss on the weld surface. Let the linguistic variables that express the weld factors be current (c), welding speed (ws), and voltage (v). From the experimental design description shown in Table 1, the range of the input and outcome variables was taken. Figure 1 shows the fuzzylogic toolbox that specifies the input and output variables. Output and Input Membership Function Definition To transfer non-fuzzy input data to fuzzy linguistic terms and vice versa, membership functions are employed in the fuzzification and defuzzification stages of a fuzzy logic system (FLS). Most of the time, a membership function is utilized to quantify a linguistic phrase. The fact that a numerical value need not be fuzzified using a single membership function is a crucial aspect of fuzzy logic. Stated differently, a value might simultaneously belong to several sets. For every input and output variable, as was previously indicated, five membership functions-very low, low, moderate, high, and very high-were chosen.

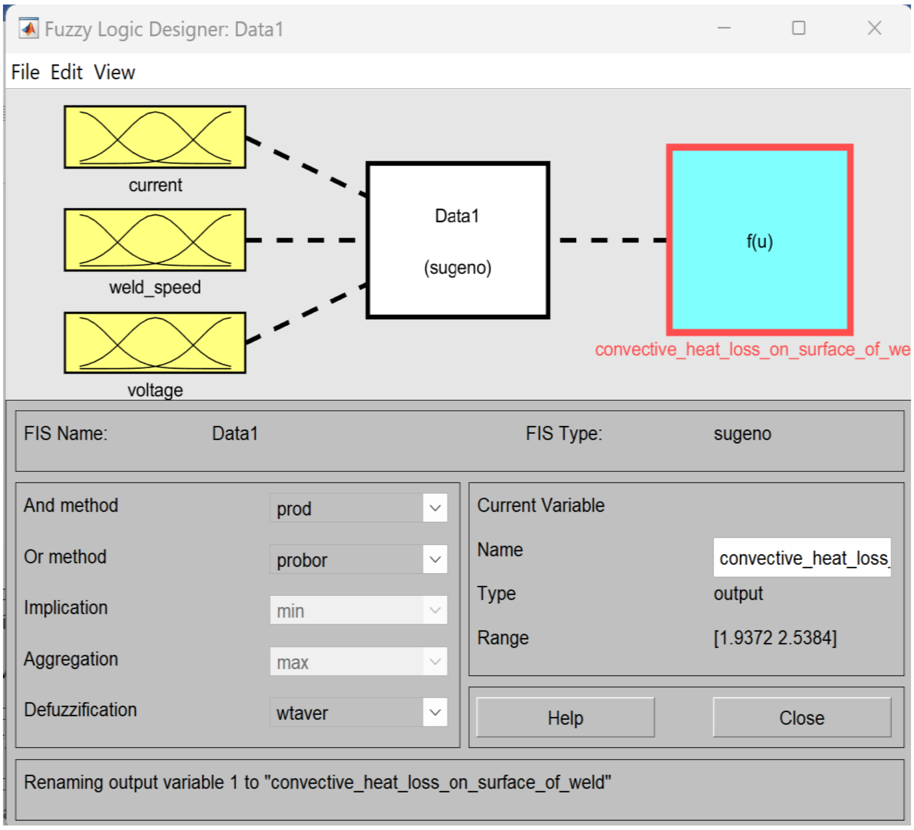

Fig 1: Defining the Input and Output Variables for Convective Heat Transfer

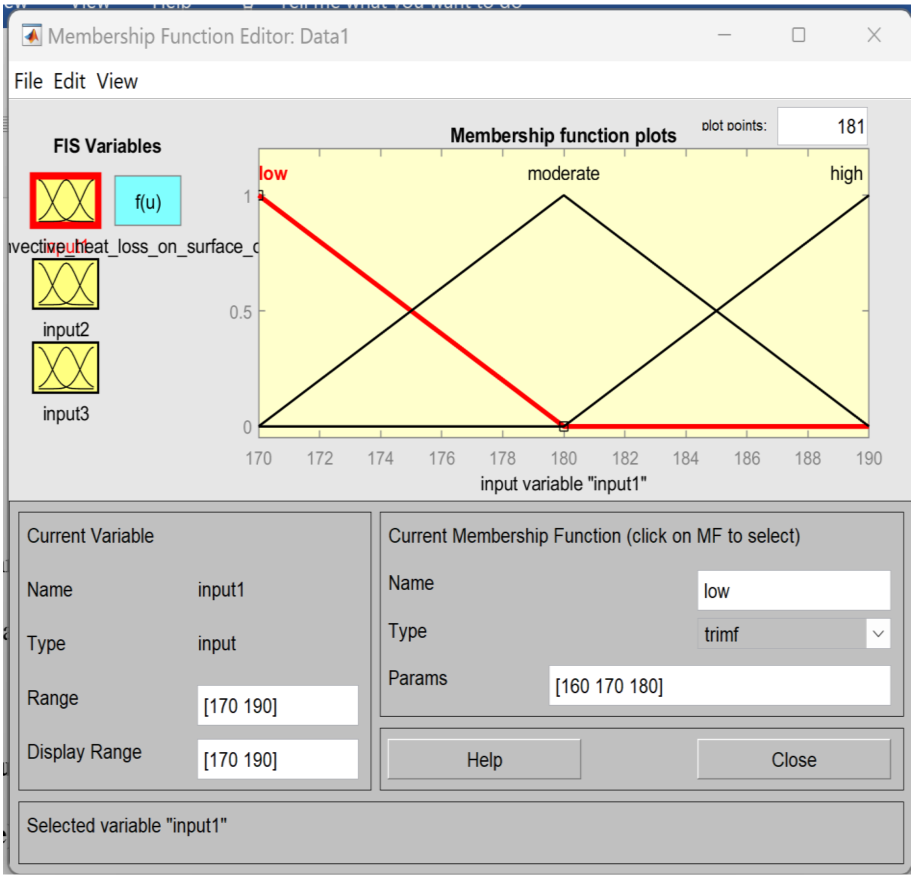

Fig 2: Definition of membership function for Current

Figure 2 indicates how current works as a membership. 160 170 180 is the membership set that determines low welding speed; the current range is indicated as [170 190]. The triangle membership function is the kind of membership function that is used.

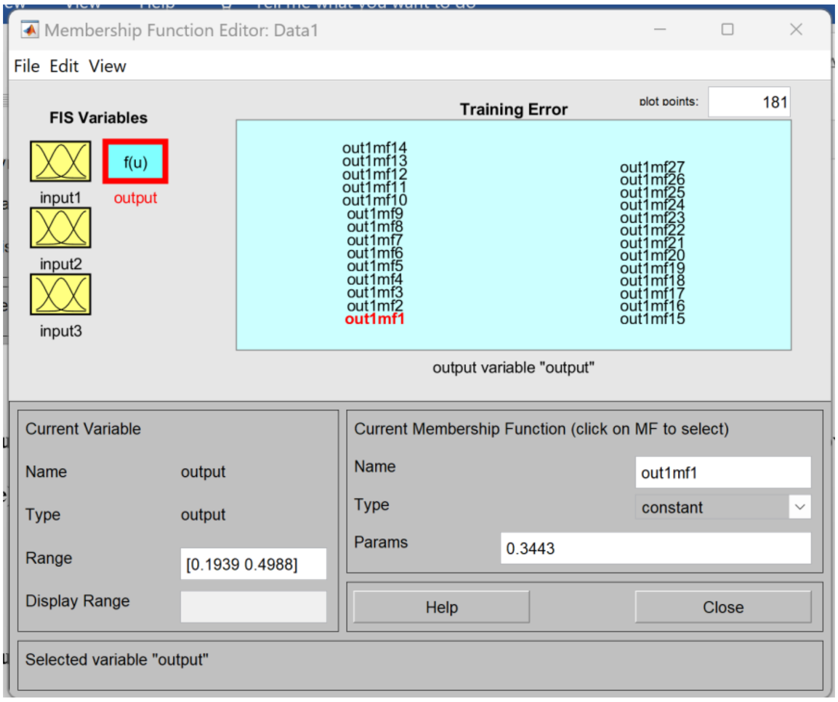

Fig 3: Definition Of Membership Function For Convection Heat Loss On Surface Of The Weld

Figure 3 displays the membership function for the weld's surface convective heat loss. The membership set is provided as [0.3443], however the range is supplied as [0.1939 0.4988].

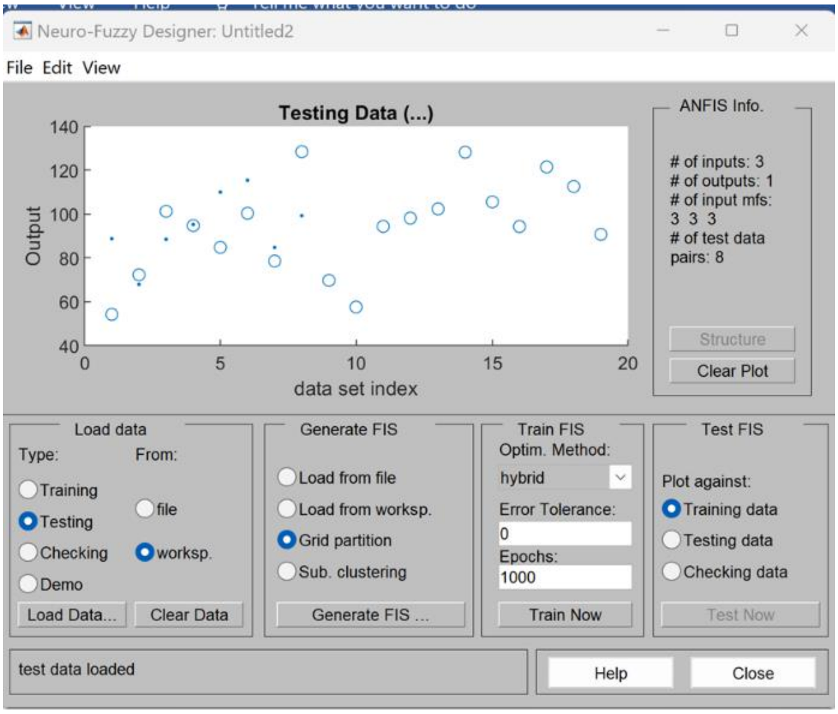

Fig 4: ANFIS Tool Box Showing the Crisp Data For Convection Heat Loss On Surface Of The Weld

Figure 4 displays the ANFIS interface with the clear data for convection heat loss on the weld surface. Grid partition was chosen, and the "generate FIS" button was pressed in order to generate the fuzzy interference system (FIS). There were three membership functions chosen for every input variable. The triangular membership function (trimf) was applied to this situation. The triangle membership function's selection can be explained by its versatility, simplicity, and capacity to define a larger range of deconstructed sets of linguistic variables.

3.2: Predicting convection heat loss on surface of the weld using ANFIS

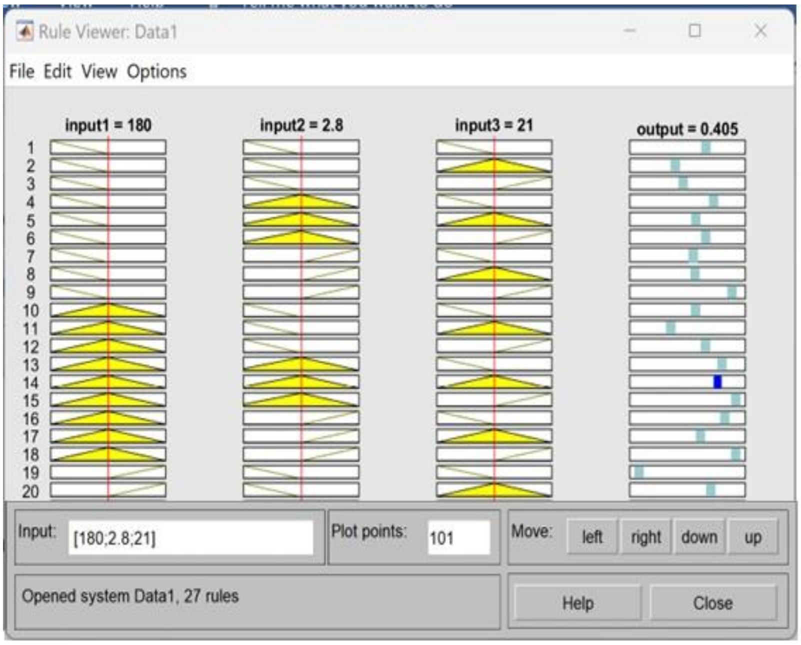

Fig 5: Prediction Convection Heat Loss On Surface Of The Weld Using ANFIS

4.2 Discussion of Results

Based on the data shown in Figure 5, it was seen that the same approach was used to obtain the result for Table 3 with a current of 180 amp, welding speed of 2.8 mm/s, and voltage of 21 volts, which anticipated convection heat loss on the weld surface of 0.405 (W/m2K). The surface plot presented in Figure 6 illustrates how welding current and speed affect convective heat loss on the weld's surface. It demonstrates unequivocally that altering any one of the input variables will substantially alter the outcome variable. Experimental values from Table 2 were chosen at random and compared with our ANFIS values corresponding to the same parameters, which are shown in Table 3, as can be seen from the graph (Figure 7: time series plot of the experiment) in order to assess the prediction accuracy of the ANFIS. Table 3 presents the randomly selected results from ANFIS for maximal convection heat loss on surface of the weld factor in comparison to the real experimental values. This shows that the ANFIS results were extremely similar to or in line with the recorded or actual experimental results. An R^2 value of 92.96% was found when comparing the experimental data to the ANFIS projected data, according to the model summary shown in Table 4.

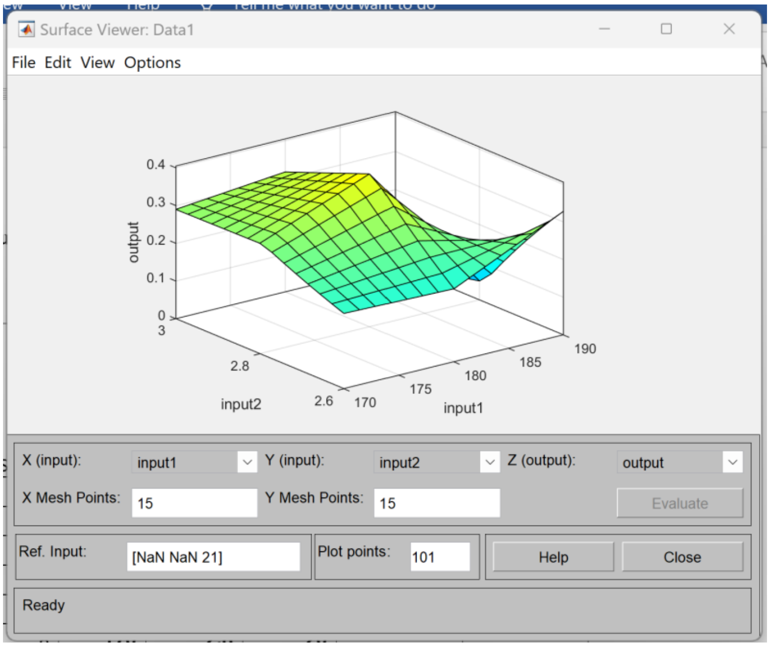

Fig 6: Surface Plot Of Influence Of Weld Speed And Current On Convection Heat Loss On Surface Of The Weld Using ANFIS

The comparison between the experimental research data on heat input and the ANFIS forecasted data on heat input is shown in Table 3.

Table 3: comparison between Experimental vs. ANFIS Convection Heat loss on Surface of the weld

S/N	Current I, Amp	Speed mm/sec	Voltage, Volts	Experimental convective heat loss on surface of weld	ANFIS convective heat loss on surface of weld
1	190	2.63	20.73	0.35	0.35
2	190	2.63	20.72	0.26	0.26
3	190	2.63	20.70	0.38	0.38
4	190	2.63	20.68	0.46	0.46
5	190	2.62	20.78	0.40	0.40
6	170	2.80	20.00	0.33	0.33
7	170	3.00	21.00	0.39	0.39
8	170	3.00	22.00	0.47	0.47
9	170	3.00	20.00	0.41	0.41
10	180	2.60	21.00	0.37	0.37
11	180	2.60	22.00	0.19	0.19
12	180	2.60	20.00	0.32	0.32
13	180	2.80	21.00	0.43	0.43
14	180	2.80	22.00	0.50	0.50
15	180	2.80	20.00	0.41	0.42
16	180	3.00	21.00	0.41	0.31
17	180	3.00	22.00	0.43	0.49
18	180	3.00	20.00	0.41	0.41
19	190	2.60	21.00	0.41	0.41
20	190	2.60	22.00	0.41	0.41

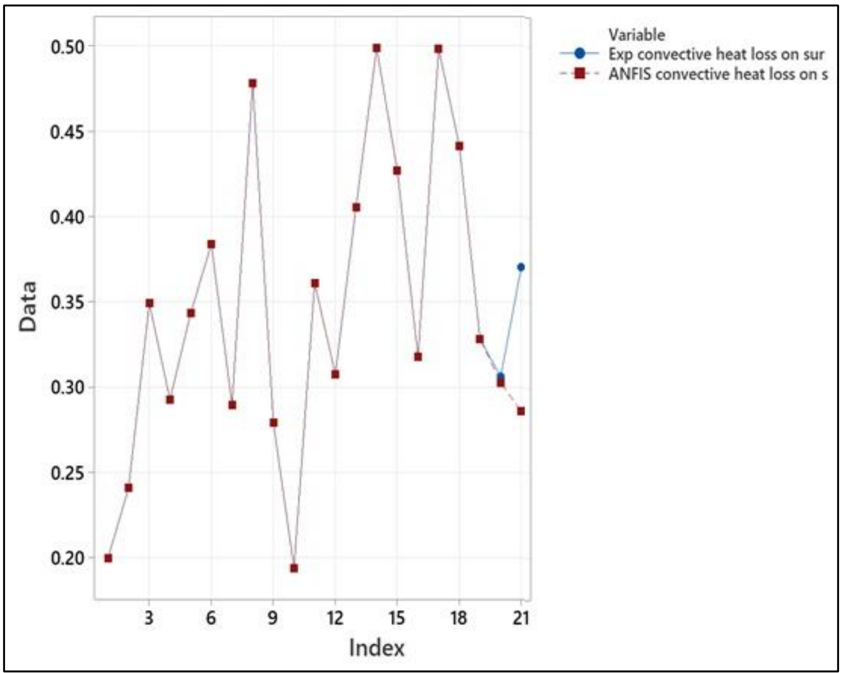

Fig 7: Time Series Plot of Exp. Convection Heat Loss On Surface Of The Weld Vs ANFIS Convection Heat Loss On Surface Of The Weld

Regression Analysis

The equation for regression Compare the convective heat loss on the weld's surface to the ANFIS convective heat loss on the weld's surface as shown in Equation (1).

Experiment convective heat loss on surface = 0.02929 + 0.9394 ANFIS convective heat loss on Surface of the weld (1)

Model summary presented in Table 4 shows an R^2 value of 92.96% obtained for the comparison of the experimental data to the ANFIS predicted data.

Table 4: Model Summary

S	R-sq	R-sq(adj)
0.0215978	92.96%	92.68%

Table 4 shows the model summary. It measures the strength and adequacy of the quadratic model. The results obtained shows that the model has 92.68% capacity to optimize convective heat loss on Surface of the weld.

Table 5: Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	0.154020	0.154020	330.19	0.000
Error	25	0.011662	0.000466		
Total	26	0.165682			

Conclusion

This research led to the effective application of the Adaptive Neuro-fuzzy Inference System to forecast convective heat loss on the weld surface during the TIG welding process.

It was successfully determined how welding speed, voltage, and current affected convection heat loss on the weld's surface. To forecast welding parameters and their impact on convective heat loss on the weld surface, an intelligent model was created. ANFIS was used to forecast the convective heat loss on the weld's surface. With a 180 amp current, 2.8 mm/s welding speed, and 21 volts applied to the weld surface, the projected convection heat loss was 0.405 (W/m2K). The results obtained shows that the model has 92.68% capacity to optimize convective heat loss on Surface of the weld. According to the study, ANFIS is a useful tool for forecasting and optimizing welding output reactions, especially convective heat loss on the weld surface, which this study has effectively proved.

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