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Fuzzy Logic Approach to Modeling Weld Bead Geometry in ARC Welding

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Abstract: Weld joint quality depends on welding process settings. High-quality welds need controlled input settings. This study looks at four input settings: arc speed, wire feed to travel speed ratio, wire feed rate, and eccentricity. Tests used a full factorial design on a mild steel joint. Bead penetration, height, and width were measured. Fuzzy logic created models for these output measures. This fuzzy model predicts the output settings. Also, weld shape accuracy was checked. The inaccuracy is below 20% for bead penetration. Bead height and width inaccuracy is usually less than 10%.

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I. INTRODUCTION

Globular transfer is the least liked GMAW method. It makes too much heat and lowers weld quality. The welds have lots of spatter. It was made as a cheap way to weld steel. It uses carbon dioxide, which costs less than argon. Its high deposition rate is a plus. It can weld at speeds up to 110 mm/s. Large, uneven drops of molten metal form on the electrode. These drops are bigger than the electrode. Gravity or short circuits make them fall onto the metal. This makes a rough surface and lots of spatter. This method works best in flat or level spots. The high heat needs thick wires and big weld pools. It also raises the chance of stress and bends.Short-circuit transfer fixes globular transfer issues. It uses less current for less heat. This lets it weld thin stuff with less stress. Metal drops form on the wire and touch the workpiece. This makes a short circuit. The arc goes out, then quickly restarts. Surface tension pulls the drop into the weld pool. This happens about 100 times a second, so the arc looks steady. This makes welds better, cuts spatter, and allows all-position welding. It has a slower rate of metal deposit. It needs amps from 100 to 200 and volts from 17 to 22. It's good for steel, but it may not work well on thick stuff. It can cause poor fusion and shallow welds.

Spray transfer is the first GMAW metal transfer method. It works well on aluminum and stainless steel. You need to use inert shielding gases. Metal moves as a fine spray. Small drops or vapor move along a steady arc. This makes little spatter and a good finish. As voltage and current rise, the transfer changes. Large globs turn into a fine spray. This method uses a lot of heat. So, it's best for flat and horizontal welding. Vertical-down is sometimes okay. It's not great for root passes. Smaller electrodes and less heat can help. The deposition rate is about 60 mm/s. Spray transfer works best for materials over 6.4 mm thick. The large weld pool and heat are easier to control.

Pulsed-spray transfer is a newer type of spray transfer. It uses pulses of current. Each pulse sends one drop, giving better heat control. This makes a smaller weld pool. The heat-affected zone is smaller, too. So, it's good for thinner materials. This process has a stable arc with no spatter. It avoids short circuits. It can weld in all positions. It works with many metals, even nonferrous ones. You can use thicker electrode wires. The deposition rate is a bit slower, about 85 mm/s. But, it's flexible and cleaner. That makes it popular. It needs a special power source. It must make 30 to 400 pulses each second. It also needs shielding gas with mostly argon and a little carbon dioxide.

II. REVIEW OF LITERATURE

Many researchers have used math models and soft computing to predict weld bead shape. These methods include neural networks, neuro-fuzzy systems, and genetic algorithms.

Chan et al. (1999) made a neural network model to better predict weld shape. Lee et al. (2000) used both regression and neural networks. They predicted back-bead shape using current, voltage, and speed.

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Sreeraj et al. (2000) used simulated annealing to set process steps and predict weld shape. They used a design to find four key shape sizes. The models were checked for accuracy, and the algorithm improved prediction.

Kim et al. (2002) created a smart algorithm with neural networks and regression. They looked at how welding steps affect bead height. This helped find the best settings for robot welding.

Kim et al. (2003) made math models to pick process steps and predict weld shape. They used current, voltage, and speed as inputs. Lee et al. (2006) showed a math model of a welding control system and its parameters. They used a sliding surface as input, which cut down fuzzy rules.

Palani et al. (2006) built a model to predict weld shape and process steps. They welded stainless steel wire to structural steel. Carrino et al. (2007) used neuro-fuzzy methods to boost output and predict weld shape in gas metal arc welding. They focused on keeping wire feed speed steady by changing welding current.

Manonmani et al. (2007) made math equations to predict weld shape. They used a design for butt joints of stainless steel sheets.

III. EXPERIMENTAL STUDY

The study used four main inputs: arc speed (N), wire feed to travel speed ratio (F/S), wire feed rate (F), and eccentricity (E). First, tests helped find good ranges for these inputs. In these tests, one input changed at a time, while the others stayed the same. This showed each input's effect.

Table 1 lists the chosen input values, units, and symbols. The tests used a full factorial design. Montgomery (2006) suggested this method. With four inputs at three levels each, there were 40 total tests . The first tests helped pick the levels for each input.

Table 1 Input Parameters Limits

Input Parameters	**Units**	**Notation**	**Factors Levels**		
			Low	**Medium**	**High**
Rotational Speed (ARC)	RPM	N	100.1	500.2	900.1
Wire Feed Rate and Travel Speed		X	30.1	40.1	50.2
Wire Feed Rate	Meter per minute	F	4.1	5.6	7.3
Eccentricity	Millimeter	E	2.2	3.7	5.3

Fig 1 Macro-Etched Weld Bead Examination

- *Dimensions of Weld Bead Geometry*

Table 2 Dimensions of Weld Bead Geometry

EXP NO	**N RPM**	**X**	**F m/min**	**E Mm**	**PENETRATION mm**	**HEIGHT mm**	**WIDTH mm**
1	100.1	30.1	4	2	1.02	4.25	10.6
2	500.2	30.1	4	2	0.74	3.76	11.6
3	900.1	30.1	4	2	0.67	3.5	12.34
4	100.1	40.1	4	2	1.21	4.75	11.18
5	500.2	40.1	4	2	0.85	4.53	13.11
6	900.1	40.1	4	2	0.75	4.15	13.91
7	100.1	50.2	4	2	1.51	5.51	12.75
8	500.2	50.2	4	2	1.01	4.92	14.03
9	900.1	50.2	4	2	0.85	4.81	14.94
10	100.1	30.1	5.5	2	2.91	4.05	10.52

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11	500.2	30.1	5.5	2	2.22	3.95	11.69
12	900.1	30.1	5.5	2	1.41	3.84	12.81
13	100.1	40.1	5.5	2	3.16	4.85	12.02
14	500.2	40.1	5.5	2	2.5	4.8	13.73
15	900.1	40.1	5.5	2	1.88	4.54	15.06
16	100.1	50.2	5.5	2	3.93	5.63	13.41
17	500.2	50.2	5.5	2	2.78	5.38	15.04
18	900.1	50.2	5.5	2	2.35	5.2	15.59
19	100.1	30.1	7	2	5.35	4.1	13.2
20	500.2	30.1	7	2	5.89	4.02	13.06

IV. FUZZY LOGIC EXPLAINED

➢ *Understanding Fuzzy Logic*

Fuzzy logic has two main meanings. In one sense, it's a type of logic. It expands on older ideas about logic. More broadly, fuzzy logic is like fuzzy set theory. This theory deals with things that don't have clear borders. Membership in a group is a matter of degree. Fuzzy logic, in its narrow sense, is part of the broader FL. Even the narrow view differs from older logic systems. A key idea in FL is the fuzzy if-then rule, or fuzzy rule. Rule-based systems have been used in AI for a while. But they lacked ways to handle fuzzy results and inputs. Fuzzy logic adds this through the calculus of fuzzy rules. This calculus helps form the Fuzzy Dependency and Command Language (FDCL). The toolbox doesn't use FDCL directly. Yet, it's a key part of how it works. Fuzzy logic solutions often turn human solutions into FDCL.

- *Fuzzy Inference System*

A Fuzzy Inference System (FIS) links inputs to outputs using fuzzy logic. FIS tries to copy human reasoning with fuzzy IF-THEN rules. The math in fuzzy reasoning is simple. Fuzzy logic is easy to change. You can add or remove rules without starting over. Fuzzy logic works with unclear data, not uncertainty. It uses membership values in fuzzy sets. For example, it uses 'He is tall to degree 0.8' instead of 'He is 180cm tall'. Fuzzy logic uses expert knowledge. It depends on those who know the system well. Fuzzy logic can mix with other control methods.

- *Fuzzy Logic Toolbox: GUI Tools*

This section shows how to use the Fuzzy Logic Toolbox GUI tools to make a FIS. The toolbox has five main GUI tools. They help you build, edit, and watch fuzzy inference systems: Fuzzy Inference System (FIS) Editor Membership Function Editor Rule Editor Rule Viewer Surface Viewer.

Table 3 Bead Width (Input Variables)

	Low Valve	Medium Valve	High Valve
Rotational speed (n) , rpm	100.1	500 .2	900 .1
Wire feed rate and travel speed (x)	30	40	50
wire feed rate (f), m/min	4	5.5	7
ECCENTRICITY (E), mm	2	3.5	5

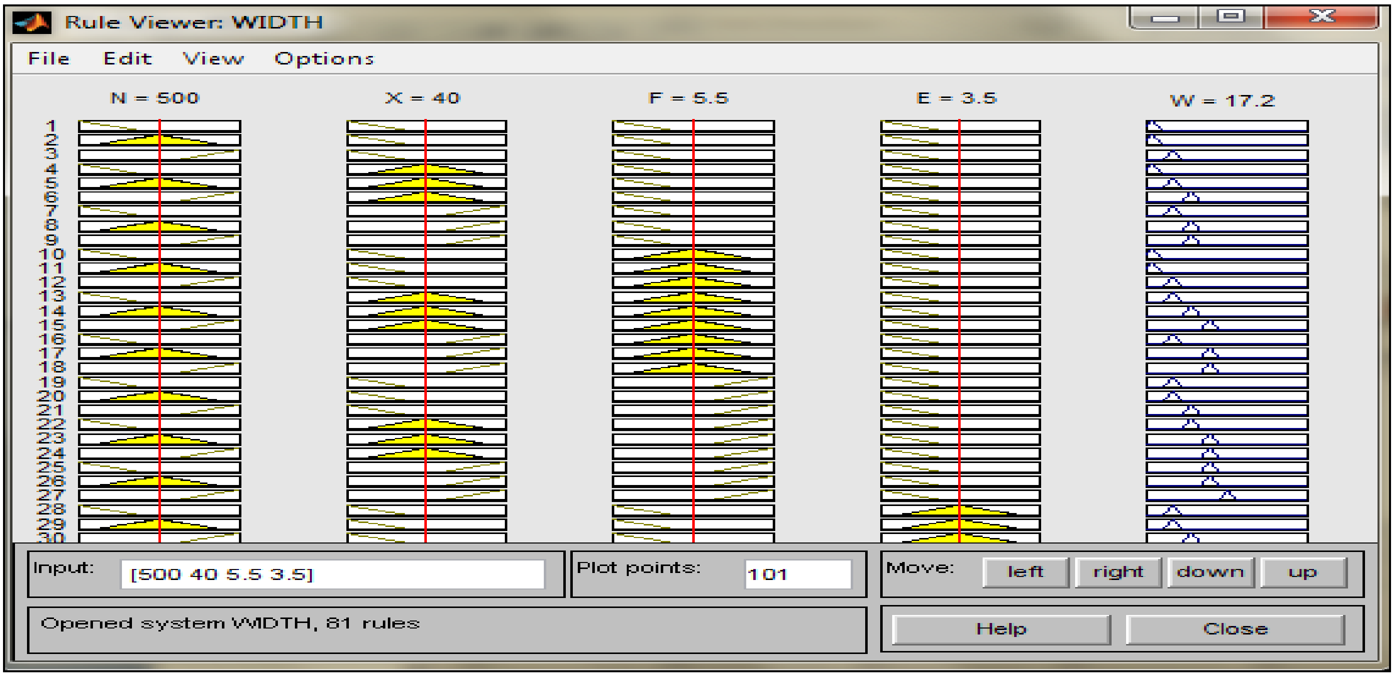

Fig 2 Rule Viewer of Bead Width (W)

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V. RESULTS AND DISCUSSION

A fuzzy model was created to predict bead width, height, and penetration using data from experiments. FIS Modeling was used, and its results were checked against experimental data. The fuzzy model's results closely matched the experimental results, showing good accuracy. The bead width error was less than 6% positive and 9% negative. The scatter diagram for bead width showed a close match to the experimental results. For bead height, the error was less than 7% positive and 8% negative. Similarly, the bead height scatter diagram closely matched the experimental results. Bead penetration error was less than 20% positive and 20% negative. The scatter diagram for bead penetration also showed a close match to experimental results.

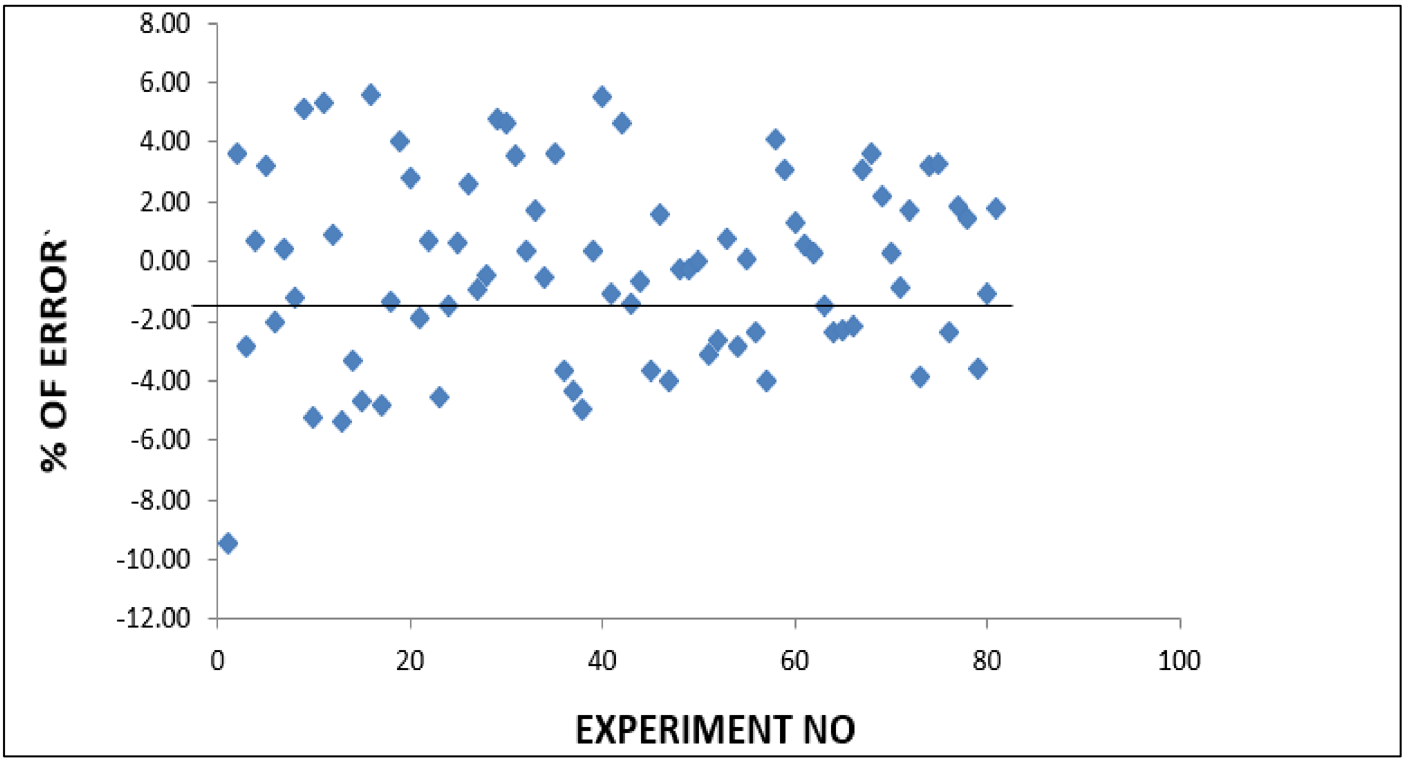

Fig 3 Error Analysis of Bead Width (W)

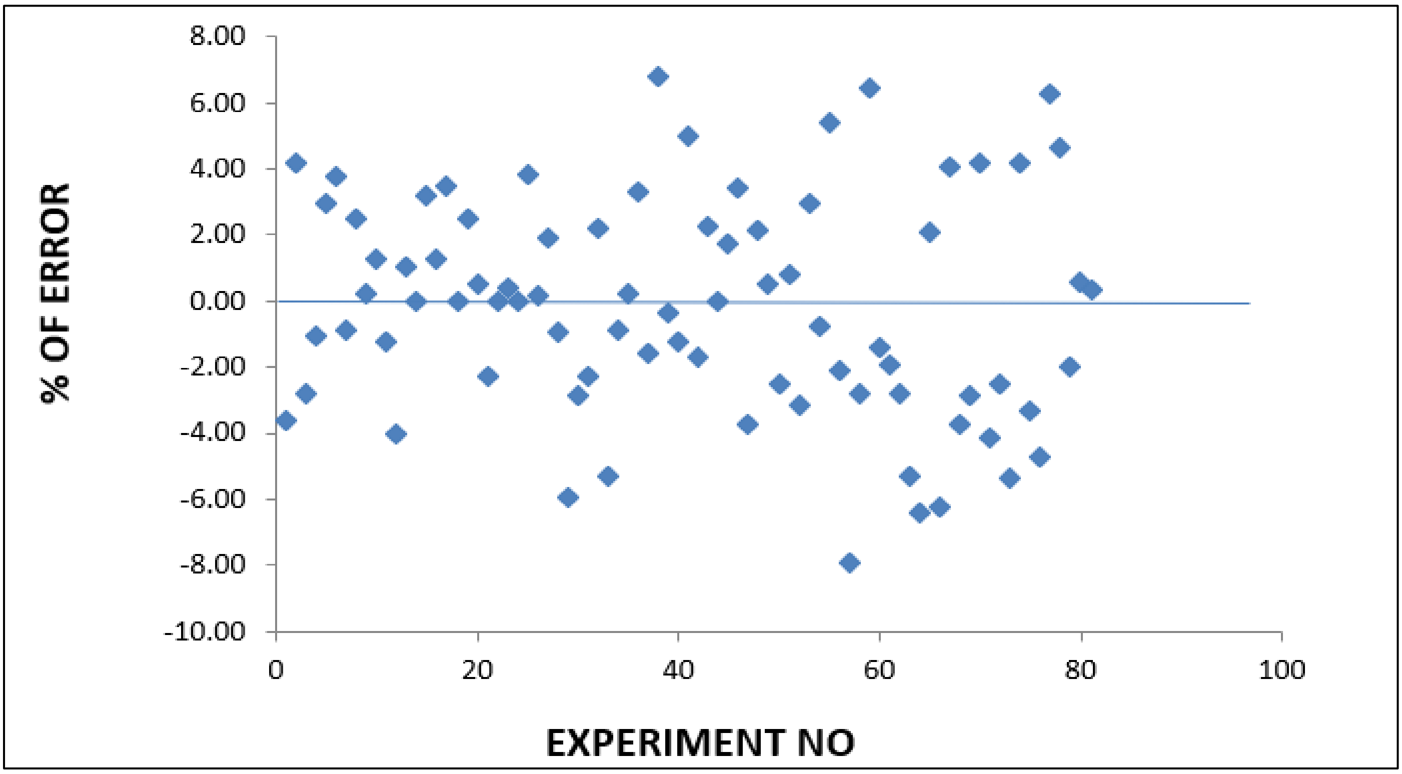

Fig 4 Error Analysis of Bead Height (H)

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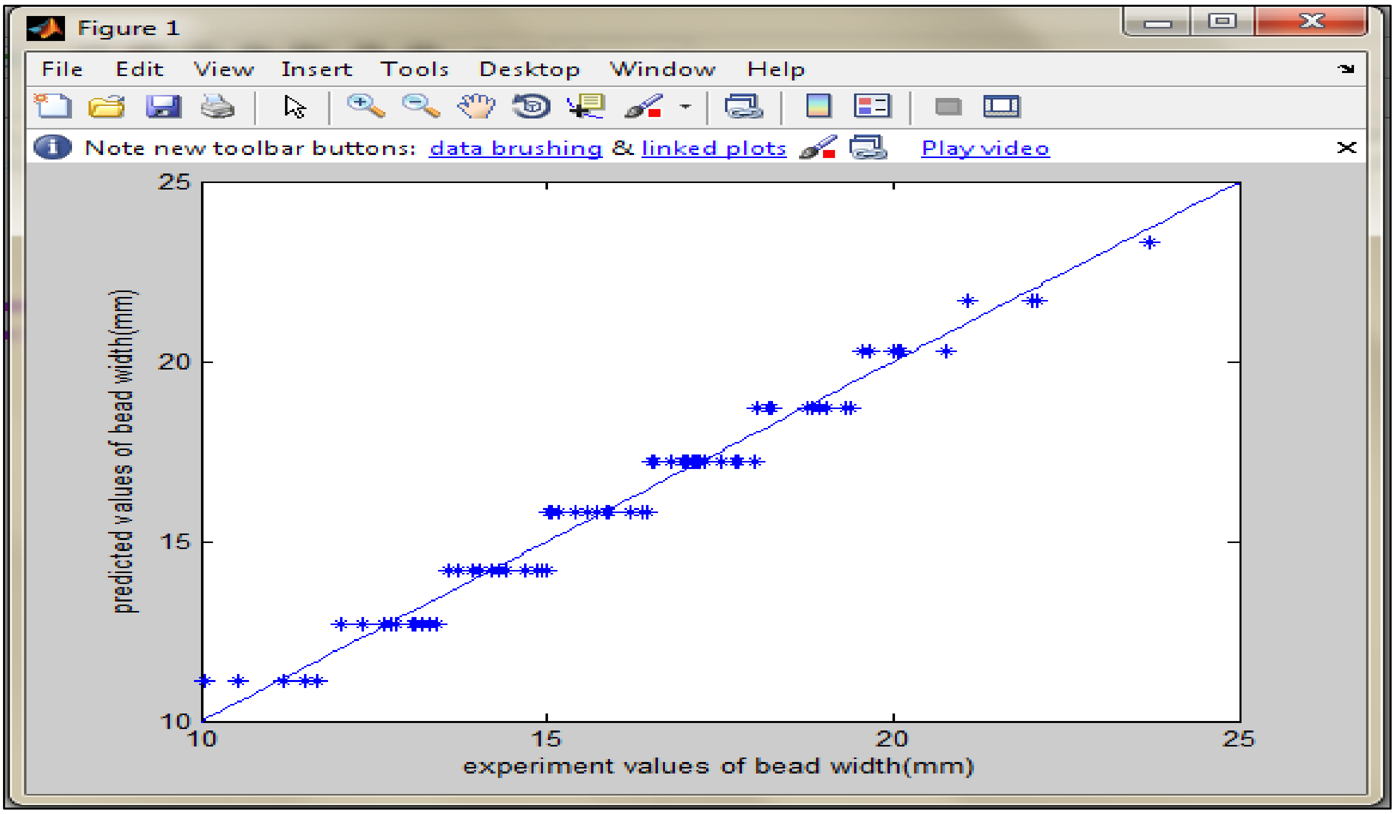

Fig 5 Scatter Diagram of Bead Width (W)

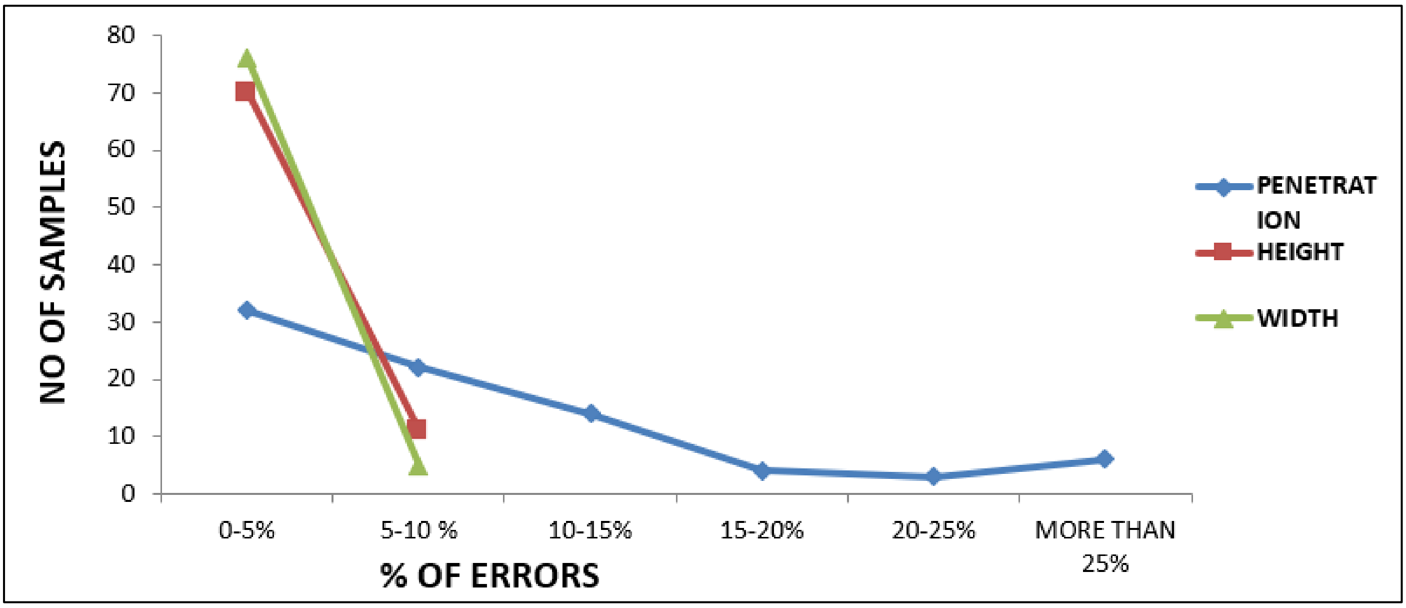

Fig 6 Accuracy Analysis of Bead Penetration, Height and Width

Weld bead size and shape are affected by process controls. Arc speed, wire feed and travel speed ratio, and eccentricity all matter. These factors change the bead's width, height, and depth. Fuzzy logic models use data to link process controls and weld shape. These models predict bead size with good accuracy. Bead width and height predictions are usually within 10%. Bead depth prediction is mostly within 20%. Scatter plots show width and height predictions are more reliable than depth. Fuzzy models are more accurate for bead width and height overall.

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