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Taguchi Method: A New Approach for Evaluating and Optimizing Parameters of TIG Welding

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Abstract

The construction and industrial sectors must improve the quality of their welds. An experimental plate fabricated of SS304L was to be tungsten inert gas (TIG) welded in this experiment, and an effort was made to enhance the mechanical properties. The Taguchi L9 orthogonal array was used to organize the experiment, and the mechanism of advancement was used to simulate the performance. The tensile strength of the welded junction rises in proportion to the amount of current that is sent through it. Here, Taguchi and flux must enhance the welding process while also studying and enhancing numerous welding factors. We can get better results and save time, which lowers the cost of the work at some level, which is favored most, by utilizing suitable welding parameters and some additional chemical flux when welding. We considered critical process factors such as current, speed, and gas flow rate for welding operations. According to the findings, the TIG welding settings of current of 175 A, speed of 6.66 mm/s, and gas flow rate of 15 L/s provide greater fluidity and improved strength.

Keywords: TIG setup, Taguchi method, L9 array, universal testing machine

INTRODUCTION

Welding unites two materials, whether they are similar or dissimilar. There are still some welding methods that are available since technological applications are under constant development. The metal itself, the heat source, the substance used to fill the space, and some sort of air protection are the four elements of welding [1]. The high-density housing metal is added to the region that has to be integrated after the welding process has begun, during which the metal warms up until it melts and is simultaneously shielded from the air to prevent oxidation. Finally, one metal piece is fabricated.

Tungsten inert gas (TIG) welding, sometimes referred to as gas tungsten arc welding, is a welding process that employs an inert gas to induce an arc between a piece of work to be joined and an inedible tungsten electrode [2, 3]. Arc welding is very reactive [4]. When excellent weld quality or precise welding performance is required, it has grown to be a preferred option for welding processes [5]. Substantial metals including stainless steel, magnesium, aluminum, and titanium may be soldered together using this method often [6, 7]. Although the proportional thickness of the incendiary material on one floor, the inadequate tolerance to different formulas, and the low productivity of the TIG welding technique are possible issues. Many arc welding procedures have been looking for ways to improve arc penetration. A second noteworthy technique is arc penetration

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enhancement strategies for TIG welding with activated flux. Production of aircraft and marine vessels employs the A-TIG welding technique to save costs band increase quality. When compared to the conventional TIG welding method, the capacity to penetrate is up to 300% higher [1]. The relevance of process parameters in weld bead shape was examined by Tarng and Yang [8] using the Taguchi technique. According to the Taguchi method's orthogonal similarity, the test is set up. The Taguchi technique was used to ascertain the precise estimate of the parameter. The Taguchi philosophy was also employed by Datta et al. [9] to establish the parameters necessary to accomplish the required weld morphology and the relative size of the region impacted by the temperature of the submerged arc. The present research work learns about numerous welding parameters [10] and advancements by employing this flux as well as the Taguchi development approach, which will help us boost the strength of our welds [11, 12].

A visit was made to a MIDC (Maharashtra Industrial Development Corporation) venue in Jalgaon. “One Industries” is located in Jalgaon MIDC with standard machine door doors, where TIG heating is set up and TIG welding process was carried out on a small plate 3 to 6 mm. Here welding is done on both sides of the plate to save time and less weld power if we do with one pass. That should increase the fluidity and intensity of welding and welding capacity and in less time and expense.

DESIGN OF EXPERIMENT

Due to intense market rivalry, companies are under pressure to develop new products and processes quickly and cheaply. A crucial technique for attaining objectives is exploratory design. A limited number of tests may be used to enhance the process using the mathematical approach referred to as design of experiments (DOE). The Taguchi technique, operational response area, and industrial design are the three basic DOE methodologies. The TIG welding process is designed and analyzed in the current investigation using the Taguchi technique [13].

Principal Design Features

The SS304L is the SS304 type's lowest carbon iteration. Although nearly mainly utilized for the 304, SS304L is favored for welding (Tables 1 and 2). It provides an excellent balance of durability, resistance to corrosion, and fabric effectiveness, in addition to offering several other advantages. One of them is utilized in almost every sector of business conceivable. This alloy is exploited to make anything from stoves to fasteners to cutlery and ballpoint pens. Machinability alloys will tend to work harder, although slower speeds and heavier feeds will lessen this tendency [11]. Chip breakers should be used since certain chips have lengthy cords. Premium machinability markings are now widely available, with brands like CarTech's Project 70 and 7000 series being only one example.

Welding

The annealing of 304 used all absorption and impedance procedures satisfactorily. It is advised to use filler metal AWS E/ER308 or 312. Due to its low carbon concentration, it produces less carbide rain at its maximum temperature, which produces concrete heat.

Hot Working

Heating progressively to 2100–2300°F should be followed while forging, heading, and equivalent hot works. To achieve the optimum level of corrosion resistance in machined products, vigorous cooling is required.

Cold Processing

Although 304L is efficiently manufactured using most cold working processes, it may require intermediate annealing to minimize cracking or tearing due to radical deformation. Any operation should be accompanied by full annealing to decrease internal tension and improve corrosion resistance.

Annealing

The process is followed by a fast cooling from 1850 to 2050°F (1010–1121°C).

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Hardening

Heat treatment provides no influence on this metal. Hardness and strength will both expand as a result of cold labor. Here metal SS304L was selected because of wide benefits. Size of plate: 610 × 450 × 6 mm (Figure 1).

Figure 1. SS304L metal plate.

Table 1. Properties of metal [1]

Metal	Stress Tensile	Strength Elongation (%)	Hardness HB
SS304L	485	40	201

Table 2. Chemical composition of SS304L [1]

UNS CODE	GRADE	Mn	P	Si	C	S	Mo	Cr	Ni	N
S30403	304L	2.01	0.05	0.751	0.029	0.029	-	18.00/20.00	8.00/12.0	0.11

Figure 2. Preparation of sample.

EXPERIMENTAL WORK

The actual experimental work is started at this step. The activities of the experimentation are explained as follows.

Cutting of Plate [Plasma Arc Cutting]

As we have a plate of SS304L of dimension 610 × 450 mm and 6 mm thickness, we had to cut it in a sample size of 60 × 150 mm (Figure 2). We required such about 20 pieces. Plasma arc cutting is the method of choice for SS304L because of the material's extremely high strength, which prevents it from being cut by any of the more traditional cutting processes. Plasma arc cutting is a method that may be used to cut stainless steel as well as nonferrous metals like aluminum with high levels of precision

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(Figure 3). This method is being utilized here for the cutting of SS304L metal plates due to the benefits described above. Plasma arc cutting is distinguished by high speeds of cutting, and it is most frequently utilized in automated cutting systems (Table 3). The cutting causes a significant increase in noise, which is manageable to some extent.

Figure 3. Metal cutting by using plasma arc machine (PAM).

Table 3. Welding parameters [4]

Current (Amp)	Gas flow rate (LPM)	Speed (mm/s)
150	10	6.66
150	12.5	3.33
150	15	1.66
175	10	3.33
175	12.5	1.66
175	15	6.66
200	10	1.66
200	12.5	6.66
200	15	3.33

Development of Oxide Flux

According to literature research, compared to other fluxes like TiO_2, silicon dioxide (SiO_2) flux powder performs better in terms of tensile strength and weld depth penetration. As a suspension medium, acetone (pure acetone for laboratory usage) and silicon dioxide flux powder with a lattice size of 40 to 150 (105–420 μm) are utilized (Figure 4). A bowl is used to create a consistent combination of acetone and silicon dioxide flow. The interface of the plates was gently coated with this mixture prior to welding (Figures 5 and 6). The coating density of the flux was about 5 to 6 mg/cm^2 or 0.2 mm thick.

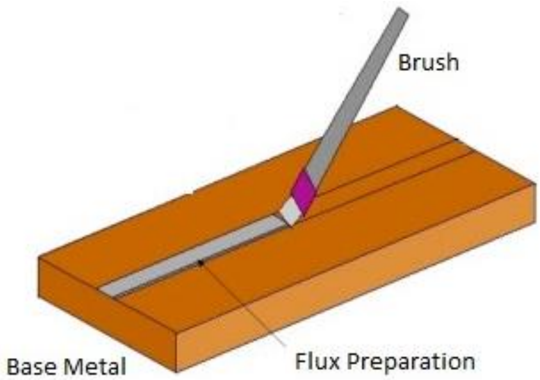

Figure 4. Flux Preparation.

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Figure 5. Welding of two pieces of SS304L.

Figure 6. Welded sample plates.

Universal Testing Machine

A universal testing machine, also referred as a global inspector, metal detection machine, or materials test frame, is used to evaluate the tensile strength and compressive strength of materials. It can test a range of materials, components, and constructions, as indicated by the word "universal" in its name [14]. Numerous testing methods need the use of test fixtures, specimen holding jaws, and sample preparation equipment (Figure 7).

Figure 7. Universal testing machine.

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The standards organization has developed a test method that discusses the setup and utilization in painstaking depth. If necessary, an extensometer can keep track of the gauge length's dynamic change in real time. The specimen is placed between the UTM's grips, or jaws. The distance the specimen travels between the machine's cross heads may be recorded even if an extensometer is not installed. This approach not only keeps track of how much the specimen lengthens or significantly reduces, but also how much the grips on the testing machine slide, as well as the elasticity of the transmission mechanisms.

When power is applied to the machine, it refuses to stop the loading process, which gradually increases in intensity. The management system and the software that is linked with it monitor the load as well as the expansion or compaction of the specimen while the test is being performed.

Test Procedure:

1. Preparing surfaces of the specimen for the best grip in jaws of UTM.
2. Placed the jaws for the plates grip in cross heads of UTM.
3. Fixed the plates in the jaws of UTM.
4. Then switched on the hydraulic systems of the UTM.
5. By operating the knob over the control panel applying the gradual tensile load on the specimen.
6. Recording readings of load applied from the display of the UTM (Table 4).
7. Repeat the procedure for each sample specimen.

Table 4. Readings of Universal Testing Machine

Current (Amp)	**Gas flow rate (LPS)**	**Speed (mm/s)**	**UTS (N/mm^2)**
150	10	6.66	400.8
150	12.5	3.33	401.76
150	15	1.66	398.5
175	10	3.33	408.7
175	12.5	1.66	409.25
175	15	6.66	424.95
200	10	1.66	392.5
200	12.5	6.66	405.2
200	15	3.33	406.25

THE TAGUCHI METHOD FOR TIG WELDING PARAMETER OPTIMIZATION

The invention of the Taguchi method can be credited to Dr. Genichi Taguchi, a master of Japanese process improvement techniques. The Taguchi method relies heavily on optimizing process parameters to maximize output without increasing costs. This is because process parameter optimization can enhance quality features and that Taguchi method-derived optimal process parameters are insensitive to changes in the environment's circumstances and other noise-related elements. In essence, traditional process parameter design is challenging to implement. Particularly as the quantity of the process parameters rises, several experiments must be conducted. Lugade and Deshmukh [5] created the Taguchi approach, which uses a special structure of orthogonal arrays to test all the program's parameter space with fewest possible trials (Table 5). To determine the difference between the experimental value and the intended value, a loss function is developed next [5]. To compute the quality characteristic's dispersion from the target value, Taguchi proposes that used the loss function. The Taguchi technique must be adjusted to assess several loss functions corresponding to various performance criteria in order to take into consideration multiple quality factors while establishing the process parameters. The loss functions in this study are weighted and included into the total loss function. The combined value of the loss function is then adapted into a signal-to-noise (S/N) ratio. The S/N ratio's qualitative quality is commonly categorized into three categories: lower is better, greater is better, and fictional is best. Based on the S/N analysis, the S/N ratio is calculated for each echelon of process parameters (Figure 8). A higher S/N ratio indicates a better level of quality, regardless of which category a quality feature falls under. The

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ideal level of process parameters is hence the one with the largest S/N ratio. Analysis of variance (ANOVA) is often conducted statistically to see whether process parameters are conclusive. This allows for the prediction of the ideal process parameter combination. To confirm the appropriate process parameters discovered by the process parameter design, a confirmation experiment is lastly carried out.

Table 5. L9 Orthogonal array [4]

Ratio	Array	Quality
1	1	1
1	2	2
1	3	3
2	1	2
2	2	3
2	3	1
3	1	3
3	2	1
3	3	2

A key component of a mathematical model is the identification of crucial process parameters. Ultimate tensile strength (UTS) is a mechanical quality that is needed in TIG welding (Tables 6 and 7). The TIG welding operator is permitted to alter the process parameters by conducting tests prior to welding. Tensile strength and weld quality fluctuate when weld pool shape alters. From literature review it was observed that most influencing process parameters on UTS are welding current, welding speed, arc gap and gas flow rate. Of these parameters, welding current and welding speed are correlated with heat input to welding process. The HAZ and fusion zone o weld pool is controlled by heat input to the welding process. The ratio of signal factors (fixed factors) to dissipation factors is indicated by the Taguchi S/N ratio (uncontrollable factors). To achieve the best result, investigation of the S/N ratio is performed to identify the best test performance or the best combination of numerous elements (Figure 9).

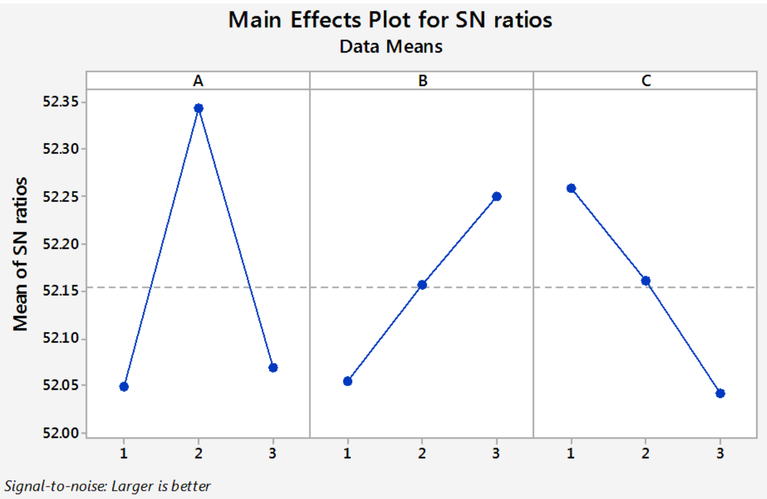

Figure 8. Effects plotted on tensile strength.

Table 6. Optimization of tungsten inert gas (TIG) welding parameters [5]

Current (Amp)	Gas flow rate (LPS)	Speed (mm/sec)	UTS (N/mm^2)	S/N ratio
150	10	6.66	400.8	52.0586
150	12.5	3.33	401.76	52.0793
150	15	1.66	398.5	52.0086
175	10	3.33	408.7	52.2281
175	12.5	1.66	409.25	52.2398

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175	15	6.66	424.95	52.5668
200	10	1.66	392.5	51.8768
200	12.5	6.66	405.2	52.1534
200	15	3.33	406.25	52.1759

Table 7. Optimization of tungsten inert gas (TIG) welding parameters with percentage of error

Current (AMP)	Gas flow rate (LPS)	Speed (mm/Sec)	UTS (with flux)	UTS (without flux)	% Error
150	15	1.66	398.5	350.6	13.66
175	15	6.66	424.95	415.78	2.15
200	15	3.33	406.25	392	3.63

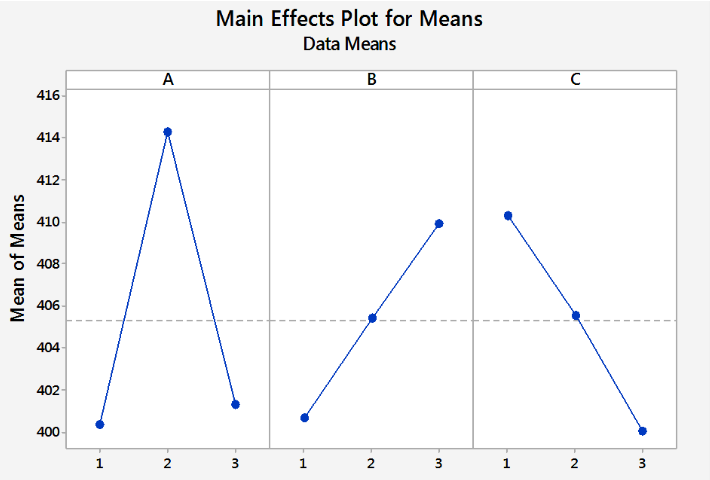

Figure 9. Main effects plotted on tensile strength for signal-to-noise (S/N) ratio.

RESULTS AND DISCUSSION

From above experimentation and optimization of welding parameters the following results were obtained.

By optimizing of above parameters, it is clear that if peed of welding is increased, flux increased in addition to this less percentage of error at moderate supply of current. As in case if 175 A current supplied (Figure 10) shows that best optimize parameters of gas flow rate 15. Better strength is obtained at these parameters with optimize percentage of error of 2.15. For the improvements of results, use different types of fluxes for the higher fluidity and higher strength of weld [15].

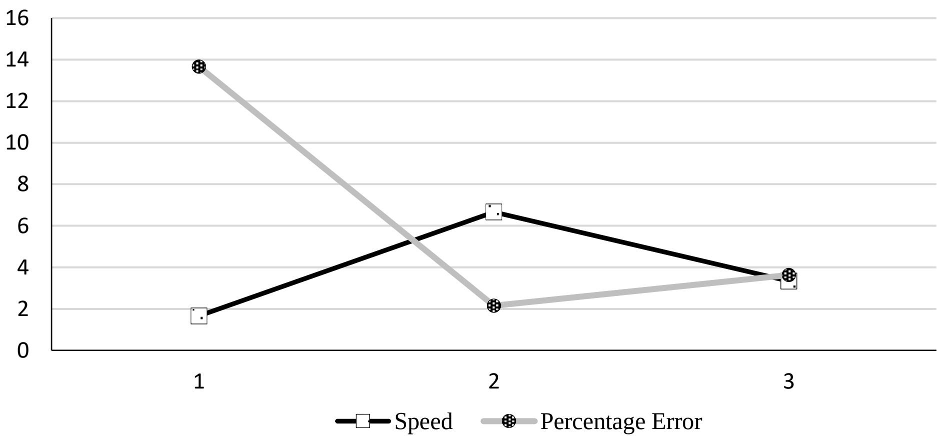

Figure 10. Speed versus percentage of error.

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CONCLUSIONS

From above results and discussion, it can be concluded that by using the parameters having current 175 A, speed 6.66 mm/s, gas flow rate 15 LPS gives higher fluidity and better strength for TIG welding.

Weld strength, or tensile strength of the weld joint, is related to welding factors like speed and current of welding. The tensile strength of the welded junction rises in proportion to the amount of current that is sent through it. When welding at slower rates, the strength of the weld is enhanced because the concentration of the current is greater. By using proper welding parameters and some extra chemical flux at the time of welding, one can get the better results, thus saving cost and time.

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