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Parametric Optimization (GMAW) for the Improvement of Mild Steel Weld Strength Using Response Surface Technique

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Abstract

In every welding operation, the Ultimate Tensile Strength (UTS) of the weld in comparison to the parent metal is the most desirable strength metric. It is necessary that the parameters of the welding process be continually examined and improved due to the growing demand for stronger weld connections in structural and industrial materials. This study's objective is to investigate the flaws in the welding procedure that the investigated industrial company employs and to come up with alternative, specially designed, and enhanced process parameters to replace the existing procedure welding protocol. If successful, this will result in improved weld results and a higher UTS. The Response Surface Methodology (RSM) was then utilized in order to optimize the suggested process parameters on the basis of a comparison to the previously published research.

The tensile strength of 200 mm x 20 mm GMAW welding plates was evaluated through the use of testing procedures. The results of the experiments were evaluated using the RSM approach, and the findings demonstrated that the current, voltage, and travel speed were the primary factors that determined the final strength of the weld. The results also show that there is a significant correlation between the values that were measured and those that were anticipated for the UTS. Maximum UTSs of 425, 450, and 475 MPa. Were achieved when welding voltages were set at 28 volts, currents were set at 240 amperes, and travel rates were set at 0.012 meters per second.

Keywords: Optimization, GMAW welding, Ultimate tensile strength, Response surface method, Contour plot, Surface plot.

1 | Introduction

The measure of mild steel weld products is critical to the manufacturing, fabrication, and construction processes. Because of their high coefficient of thermal expansion, these materials are prone to deformation [1]. The welding process parameters established by modern industries and included as part of their distinctive processes have a significant impact on the success or failure of such finished products. The demand for stronger, more dependable welds with better quality control is continually increasing. Most manufacturers, on the other hand, followed the same welding techniques and specifications [2].

Gas Metal Arc Welding (GMAW) technique is a fast and cheap method of joining two materials permanently. It is more suitable for design flexibility and construction of the plan structure. This

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process is use in almost all metal manufacturing process, such as in jet engines, pipelines, automobiles, ships and buildings [3].

Mild steel accounts for a significant share of total steel output [4]. They are the most important steel utilized in the petroleum and petrochemical industries, accounting for more than 98% of construction materials [5]. Mild steel has a wide range of applications, including petrochemical facilities, oil and gas storage tanks, and transportation pipelines, due to its moderate strength, good weldability, and formability [6].

Sound weld is a key factor for industries to maintain a universal competition in the present day fast-rising environment, traditional welding process must be more adaptable, efficient and flexible [7]. GMAW is the most commonly used welding process over others because of ease of operation, simple, less expensive and has an efficient output. Its operation cut across automobiles, ships, oil and gas, petrochemical and building application. The weld strength of a GMAW is directly influenced with the amount of current, voltage, rate of gas flow and wire diameters. Other factors such as torch angle and plate thickness are also critical in achieving a sound weld, as a result it is necessary researchers identify these idea parameter standard values for optimum weld quality [8], [9].

The GMAW welding technique is the idea welding process for overcoming the limitations of employing short electrode lengths and the incapacity of the submerged-arc welding procedure to weld in a variety of positions. This process has made it possible to weld joints in the thickness range of 1-13 mm in all welding situations by properly modifying the process parameters [10], [11]. This process is use in welding several engineering materials such as carbon steels, low alloy and high alloy steels, stainless steels, aluminum, and copper alloys, as well as titanium, zirconium, and nickel alloys [12], [13].

Optimized parameters result in the production of flawless welds with enhanced mechanical and metallurgical properties. In order to evaluate elusive components using a reliable experimental model, there is a tendency toward employing measurable systems, such as the Response Surface Methodology (RSM), which is one of the fundamental uses of Design of Experiments (DOE) [14], [15]. Using RSM, it is feasible to assess and improve the input parameters for weld characteristics and obtain the desired outcomes. Chikhale et al. [16], who investigated the mechanical performance of AA 6061-T6 via metal inert gas welding and considered welding current, arc voltage, and wire feed speed as welding parameters, found that welding current has the greatest effect on the Tensile strength, depth of penetration, and toughness of weld joint. Rizvi et al. [17] used the Taguchi method to MIG welding during the bonding of IS2062 steel, and their results suggested that welding voltage and welding current had the most impact on the tensile strength of the welded joint, while gas flow rate had the least impact.

Hooda et al. [18] developed a response surface model to evaluate the tensile strength of a joint comprised of inert gas metal arc welded AISI 1040 medium carbon steel. Several input factors, including welding voltage, current, wire speed, and gas flow rate, were considered. To organize the experiment, a Central Composite Design (CCD) matrix was used. According to the results of the experiment, the optimal values of process parameters such as welding voltage (22.5 V), wire speed (2.4 m/min), and gas flow rate (12 l/min) for maximum yield strength (in both the transverse and longitudinal directions) are 22.5 V, 2.4 m/min, and 12 l/min, but the current value is 22.5 V, 2.4 m/min, and 12 l/min (190 A and 210 A). Various mechanical tests are used to assess the strength or other properties of engineering materials.

A tensile test may determine mechanical characteristics such as yield stress, ultimate tensile stress, modulus of elasticity, and ductility. It includes applying a tensile tension to a sample of material and dragging it along a single axis until it breaks. For tensile testing metals, the American Society for Testing and Materials (ASTM) recommends using either a cylinder or a flat specimen. Typically, the shape and size of testing specimens are determined by the product form in which the materials will be employed or by the amount of material available for sampling. When the end product will be a plate or sheet, the shape of the specimen should reflect this. For specimens having a circular cross section, extruded bars, forgings, and castings are optimal. Sada [19] predicted and adjusted the weld strength parameters (tensile strength and hardness) of a gas tungsten arc welded 10mm thick mild steel plate using RSM. The author analyzed the mechanical properties of the weld input parameters and their relationship to the bead geometry in order to identify which values would provide the requisite weld quality. Current and gas flow rate had the biggest influence on tensile strength, whereas gas flow rate and filler rod had the most significant effect in determining hardness.

Etin-Osa and Ebhota [20] used RSM to predict the weld tensile strength of TIG mild steel welds in order to get the best potential outcomes. Several inputs are considered, including current, voltage, and gas flow rate. Using the ideal process parameters of 120.00 Amp of current, 20.00 V of voltage, and 12.00 L/min of gas flow rate, the weld tensile test yielded 596.218 MPa with a desirability value of 95.70 percent. Imtiaz et al. [21] investigated the mechanical properties of a friction stir welded butt joint arrangement of Polycarbonate, and then optimized the combination of process parameters (traverse speed, rotational speed, and tool shape). The major objective is to demonstrate how modifying the process parameters increases the overall strength of the joint. The highest Ultimate Tensile Strength (UTS) of 51,299 MPa was attained by butt joints created with a traverse speed of 14 mm/min, a rotating speed of 1700 RPM, and a basic cylindrical conical tool form, as shown by the data. Jafari and Hajikhani [22] evaluated a multi objective decision making for impregnability of needle mat using design of experiment technique and RSM while Prastyo et al. [23] sought to lower the cost of Milkuat LAB 70 ml bottles using optimal parameter setting and the Taguchi method. Onyekwere et al. [24] used experimental design and optimization techniques to determine the ideal processing parameters for bamboo fiber polyester composites. With a value of 158.23J/cm, the impact strength was found to be ideal with mercerization treatment and 30wt% fibre content. Using the ideal parameter settings of the mercerization procedure at a fibre content of 50 wt%, a flexural strength of 62.7 MPa was attained. Ogbeide et al. [25] predicted the tensile strength of butt joint of mild steel weldment using Tungsten Inert Gas (TIG) and RSM.

The result revealed that the current and load has a very strong influence on the tensile strength.The maximum tensile strength was attained at 450 Mpa with a welding Voltage (V) of 24 V, current 170 A and gas flow rate 0f 13 lit/min respectively. To get the best potential tensile strength, the mercerized-acetylation procedure should be used to a material containing 50 wt% fibers. Tensile strength of 72,96 MPa, there was no statistically significant difference between mercerized and mercerized-acetylated fiber composites in terms of flexural strength, tensile strength, and impact strength ($P>0.05$). Several prospective routes for future investigation of welded joints and their effect on materials have been studied.

The European Federation for Welding, Joining, and Cutting (EWF) and other international engineering and welding organizations are eager to engage in research and development to create better processes for creating acceptable weldments [26], [27]. Artificial neural networks, fuzzy logic, finite elements, Taguchi, and evolutionary algorithms, among others, have all been utilized by experts to optimize process parameters because it has been found that employing the best process parameters significantly affects the final quality of the weldment [28]-[35].

The GMAW technique was utilized in this study to join steel pipes in a multinational industrial firm that operates in the upstream and downstream of Nigeria's oil sector. For more than two decades, the company had always used their established protocol with the same process parameters for its pipeline welding procedures, but they were always constrained by the fact that the welded structures could not achieve their specified life span due to unjustifiable structural breakdowns [2]. The cause of these failures was discovered to be low weld strength in comparison to the source metal. Following a thorough brainstorming session with specialists, management determined that the established process was insufficient, emphasizing the need for stronger and more durable welds. They established that the need for improved weld strength can be reached by managing welding process factors at the source and changing their established procedures, which is why this research was conducted [2].

This study examines mild steel weld strength optimization using the response surface approach. The method has been shown to be a powerful tool for enhancing the quality of the entire process by cost-effectively minimizing variance while also optimizing the welding process parameters.

2 | Materials and Methods

This study created weld deposits using the GMAW technique. Ferrous and nonferrous metals are usually welded using this welding technique. Weld deposits were created using mild steel electrodes that were 350 mm long and 4.5 mm in diameter on the GMAW equipment, which can be modified to different welding conditions as necessary. These weld deposits were shaped on the lathe machine to provide tensile specimens of 200 mm in length with a diameter of 20 mm for all the tensile tests specimen. To determine the steel stress-strain curve, standard specimens are subjected to tensile tests, as shown in *Fig 1*. The measurements in *Fig. 1.* (in mm) that were used for the tensile testing were machined from all-weld metal deposits.The stress-strain curve was used to determine each weld specimen's UTS.

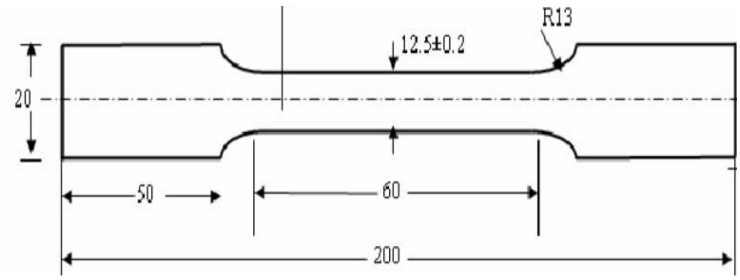


Fig. 1. Tensile test specimen.

The range of the process parameters is shown in *Table 1*. The table illustrate the varying current, time, travel speed and voltage at different leveling codes which was used to generate the experimental runs.

Table 1. Process parameters and their levels.

Sr No	Parameters	Notation	Codes	Units	Level Coded		
					1	2	3
1	Current	I	A	A	170	196	240
2	Time	t	B	min	1	1.7	2
3	Travel Speed	TS	C	m/s	0.0062	0.092	0.012
4	Voltage	V	D	v	23	25	28

The variables used were current (x1), travel speed (x2) and voltage (x3) each at level codes 1, 2, and 3. These limits were set based on the pilot study carried out prior the experimental runs. The actual levels of the variables for CCD experiments were selected based on the initial levels as the center points. A total of 27 experimental trials generated by the design expert 11.1.0.1 software adopting the CCD were performed. The data of the UTS is illustrated as show in *Table 2*. This data where obtained at varying current, time, Travel speed and voltage.

Table 2. Experimental trials data for the composite design experiments.

Run Order	Current (A)	Travel Speed (m/s^2) (C)	Voltage (V) (D)	Ultimate Tensile Strength (Mpa)
1	3	3	3	376
2	3	1	3	342
3	3	3	1	385
4	2	2	2	381
5	1	3	1	412
6	3	1	1	342
7	2	2	2	365
8	2	1	2	352
9	3	3	3	356
10	2	3	2	341

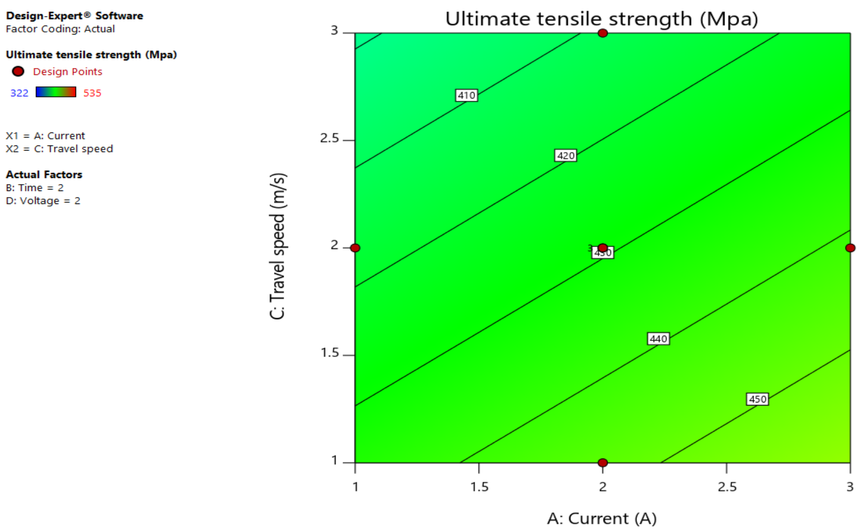
Table 2. Continued.

Run Order	Current (A)	Travel Speed (m/s^2) (C)	Voltage (V) (D)	Ultimate Tensile Strength (Mpa)
11	1	2	2	386
12	1	3	3	385
13	3	1	3	381
14	2	2	1	371
15	3	3	1	378
16	2	2	2	384
17	1	3	1	322
18	2	2	2	388
19	1	3	3	413
20	2	2	3	341
21	3	2	2	384
22	1	1	3	396
23	1	1	1	322
24	3	1	1	416
25	1	1	3	408
26	1	1	1	383
27	2	2	2	416

3 | Result and Discussion

The *Figs. 2*, *3* and *4* presents the contour plots(a) and the 3D response surface plots(b) between the varying parameters such as current, travel speed and the voltage response to the UTS within the experimental conditions established by the RSM matrix. The influence of current and travel speed on the slice of gas flowrate is shown in *Fig. 2*. The slice has three center points, which are denoted by a dot in the middle of the contour plot. The estimated optimization region of the weld UTS can be observed at max. 450 MPa as depicted in *Fig. 2*. It also demonstrated that as the weld travel speed increased, the weld current had a significant effect on the tensile strength. *Fig. 2* depicts a 3D surface plot that depicts the relationship that exists between the input variables (current and travel speed). As the current and travel speed increased, so did the tensile strength until a point when additional increases in current and travel speed resulted in a drop in the material's UTS. The green region is an indication of the tensile strength area of higher optimization. The maximum value UTS attained at this point is 425 MPa.

The contour plot in *Fig. 3* shows the predicted optimization region of the weld ultimate tensile test. The green region indicates that current and voltage had a stronger effect on the tensile strength. As a result, an optimal weld ultimate test value of 450 MPa was established. The progressive increase of the input variables increases the tensile strength of the material but as it reaches a certain point, the material UTS begins to decrease.



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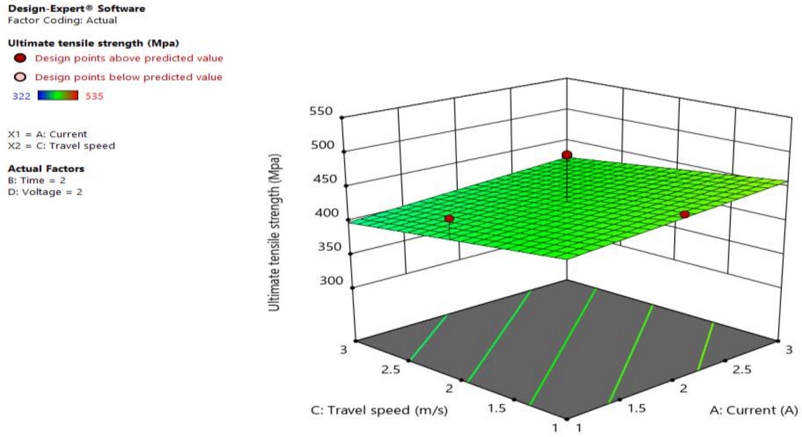

Fig. 2. Contour plot and response surface plot showing the effect of current and travel speed to the UTS.

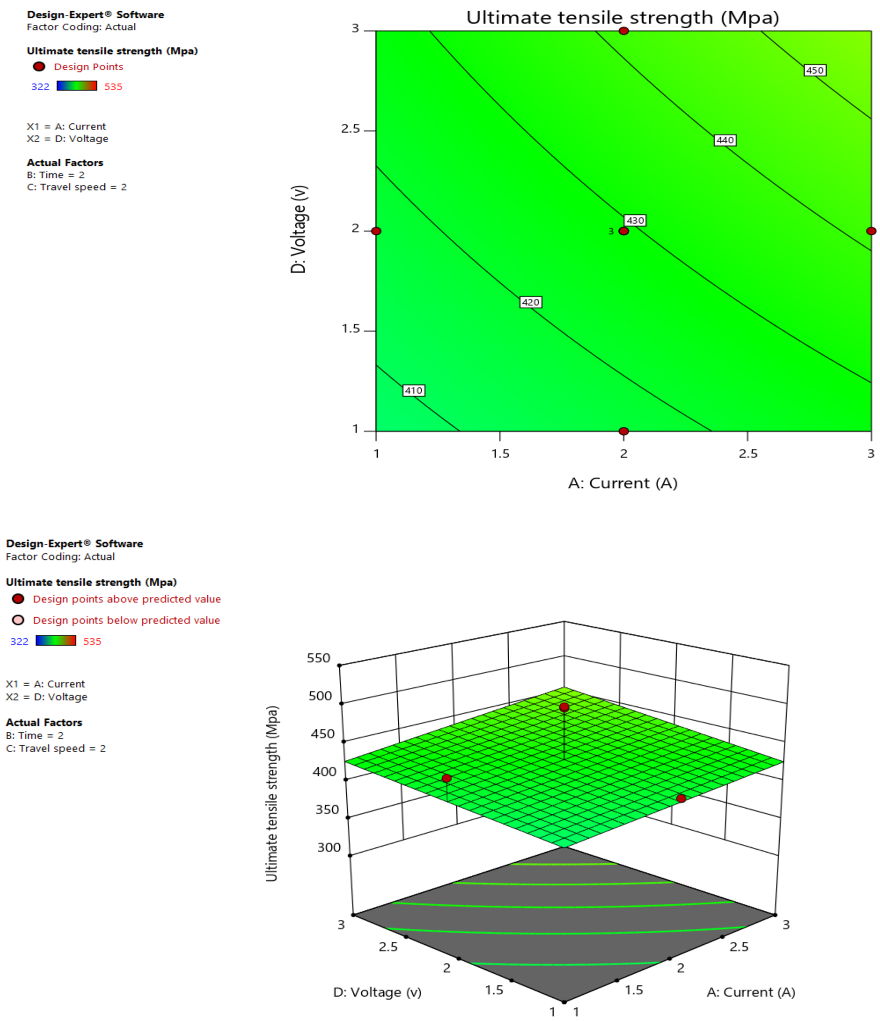

Fig. 3. Contour plot and response surface plot showing the effect of current and voltage to the UTS.

Fig. 4 depicts a three-dimensional interacting surface plot of voltage and travel speed against tensile strength. The plot *Fig. 4* shows that the tensile strength initially increases up to a certain limit when the values of the corresponding parameters increase. The plot also shows that when the voltage is low and the travel speed is fast, a larger value of UTS is obtained. In contrast, at high voltage and travel, the material does not settle adequately, resulting in porosity in the weld joints. At maximum voltage and travel speed, the ideal UTS was 475 MPa.This result has earlier been reported in the study by [2], [36], [37] which are congruent with our investigation,this finding shows that there is a significant improvement using the new optimal process parameters obtained from applying the RSM.

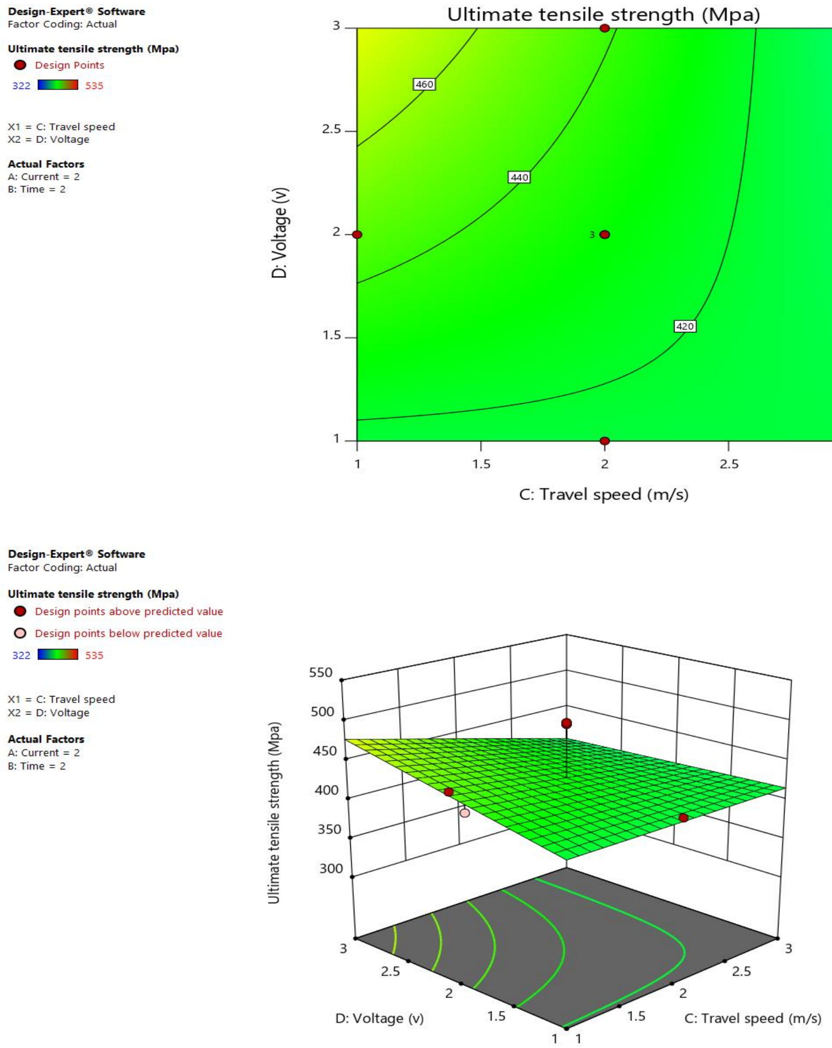

Fig. 4. Contour plot and response surface plot showing the effect of voltage and travel speed to the UTS.

Fig. 5 is use to illustrate the response of predicted and actual values of the UTS, the result indicates a strong correlation between the experimental and predicted values of the UTS. The regression analysis with R^2 of 0.9998 demonstrate the strength of response surface method and its ability to maximize the weld tensile strength.

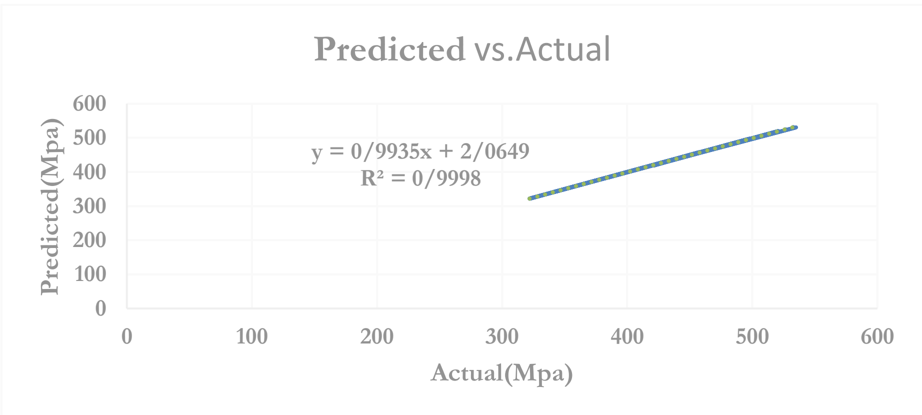

Fig. 5. Predicted against actual for a UTS response (MPa).

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4 | Conclusion

In this study, the UTS of the weld was optimized and predicted on mild steel welded samples using the GMAW welding procedure. The response surface technique was used to determine the material's UTS. The results reveal a simultaneous increase in UTS when all of the parameters (current, voltage, and travel speed) increase. However, after a specific limit, a downward trend with subsequent simultaneous increases in the values of the examined parameters was seen. As a result, when the welding voltage is 28 v, the current is 240 A, and the travel speed is 0.012 m/s, the UTS reaches optimum values of 425, 450, and 475 MPa.

Conflicts of Interest

Authors do not have any conflicts of interest.

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