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Parametric Prediction and Optimization of Mild Steel Geometry Composition Using TIG Welding Methods

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The research focused on the application of the tungsten inert gas (TIG) welding method on mild steel metal materials and its optimization of the welding input factors along with its mechanical response parameters using the response surface method (RSM). The study has reviewed many research works alongside works of literature related to the study, and also revealed that the specific studied mild steel weld bead geometry mechanical properties on its weldment have not been studied to the best of the researchers' knowledge. The material under study is IS 2062, why the method applied for the analysis is the response surface method of optimization. The result shows the optimal solutions of both the input factors and the response parameters. The optimization results show that the optimal solutions for input process factors are: a gas flow rate of

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16.00m3/s, welding speed is 113.221m/s, welding voltage is 18.00V, and welding current is 217.914A. The optimization results for the response parameters are; 344.628MPa for Hardness strength, 331.042 MPa for Yield strength, 25.272% for percentage Elongation, 452.780 for ultimate tensile strength, and 409.484 MPa for shear stress, and 118.00 J for impact energy response. The overall desirability of the models developed to achieve the optimal solutions result is 78.41%. The results will serve as bases for mild steel companies and industrialization. The research will also serve as a decision-making system in engineering and industrialization.

Keywords: Optimization; response surface method; mild steel; bead geometry; Tungsten Inert Gas (TIG); Welding.

1. INTRODUCTION

Nowadays Industry and its economy, metals, and steel have been employed for domestic, agricultural, construction, and several other purposes due to their variations in ductility, corrosion, and rust resistance, and its other properties that make the material unique and irresistible materials in Industrialization. The industrialization world utilizes these materials mainly because of their mechanical properties as well as their excellent corrosion resistance [1-3]. Industrial use or application of the present research is so essential and numerous in the field of engineering because of its usability in construction, fabrication, structures, buildings, agriculture, and domestic application [3]. “Welding is a fabrication or sculptural process that joins materials, usually metals or thermoplastics, by causing coalescence. This is often done by melting the workpieces and adding a filler material to form a pool of molten material (the weld pool) that cools to become a strong joint, with pressure sometimes used in conjunction with heat, or by itself, to produce the weld” [4]. “Tungsten Inert Gas (TIG) welding is one of the most widely used processes in the industry. The input parameters play a very significant role in determining the quality of a welded joint. Weld geometry directly affects the complexity of weld schedules and thereby the construction and manufacturing costs of steel structures and mechanical devices. Therefore, these parameters affecting the arc and welding” [1,2] should be estimated and “their changing conditions during the process must be known before obtaining optimum results; in fact, a perfect arc can be achieved when all the parameters conform” [5]. “Weld bead geometry is severely negatively affected by the occurrence of the undercut phenomenon. Weld bead geometry defects not only affect the appearance of weld beads but also cause a severe stress concentration at the weld edges, which has a great effect on the reliability of the weld joints. Whatever the category, insufficient penetration of molten weld metal which is a major cause of undercuts, lowers the strength of the weldments, and this has led to structural failures of engineering projects. Major structural failures could lead to significant safety hazards” [6]. The study literature gap shows that the selected mild steel materials (IS 2062) mechanical composition properties and their application of tungsten inert gas to produce weldment have not been studied. The study reveals an experimental study of the parametric prediction and optimization of mild steel geometry composition using TIG welding methods.

2. LITERATURE REVIEW

Achebo and Omoregie, [7] determine “the relationship between the input parameters and the output parameters, and the application of Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) has successfully used to optimize the input process parameters which has produced the most desired mechanical properties”. Achebo and Salisu [6] show that “the use of the Taguchi method has being able to reduce the depth of undercut as shown in this study”. Izzatul, [8] performed “experiments on the effects of different parameters on welding penetration, The hardness measurement, and microstructure was measured in mild steel of the base metal by using robotic gas welding” [1,2]. “The changes in welding process parameters have influenced the effect of the microstructure of weld metal. As increased welding current, welding speed, and arc voltage on the grain size of microstructure”. Achebo, Ezeliora, & Umeh, [1] research on statistical evaluation of the impact strength on mild steel cladding weld metal geometry. Okolie et al. [9] explore the optimization of a soap production using the response surface method (RSM) to show the optmal production mix of the soap raw materials. Ezeliora, Nwakobi & Aguh, [10] explained the appraisal of products production quantity optimal solution [9-12] for plastics in small and medium scale manufacturing industries. Ezeliora, Okoye & Mbabuike, [11] investigates the prediction and optimization of production quantities in Innoson manufacturing industry. The results show the optimal solutions of the products under study. Ezeliora, Umeh, & Dilinna, [12] explore the optimizarion of products production variables by using a plastic manufacturing industry as a case study. The results show the optimum solution for the produtionprocess of the plastic products in the system

2.1 Knowledge Gap

The research has reviewed several studies along with literature on mild steel materials and the optimization of its weld bead geometry, but no researcher has completely experimented with the mechanical properties of the weld bead geometry on the selected mild steel material. The researchers, therefore, try to enhance the necessary mechanical properties and their impact on the weld bead geometry. This serves as the knowledge gap.

3. MATERIALS AND METHODS

3.1 Research Method

The research method adopted in this work is a quantitative research approach. The parent material is characterized and analyzed to unveil the chemical compositions of the mild steel. The results of the mechanical composition properties of the base metal serve as the response parameters of the experimental trials. The application of response surface method (RSM) is used for the analysis of the experimental trials. The statistical analysis, results, and optimization solutions of the input process factors and the response parameters were revealed and recommended.

The importance of the research method is to optimize the experimental trials of both the input factor and the response.

3.2 Work Material

The work material used for the present work is a mild steel plate of IS2062 E-250 the dimensions of the workpiece specimens were cut into 60 x 10 x 10 by machining. The square butt joint configuration was prepared according to welding standards. Argon inert gas was used as shielding gas. The filler metal was an ASW classification E71T-1C with a 1.2 mm diameter electrode. The chemical composition and mechanical composition properties of base metal & filler metal are listed in Table 1 & Table 2 respectively.

Fig. 1a shows the samples of mild steel plates of 60mm by 40mm by 10mm specimen sample used for the experimental trials. The number of specimen trials produced is twenty-five (25). The specimens are cut in a v-shape and welded. The weld bead geometries are tested for their hardness and other mechanical properties.

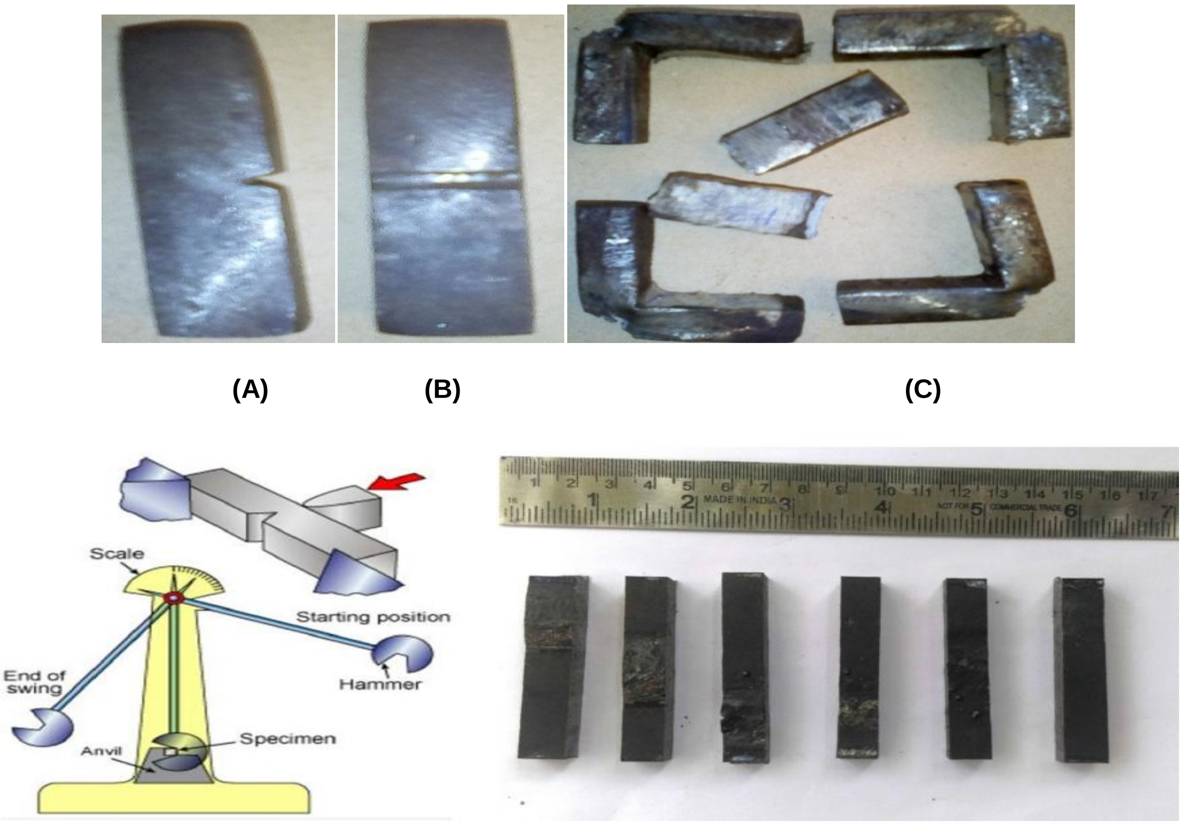
For the impact energy test, the weld bead geometry is cut, machined, and filed to the specific dimensions of 60mm by 10mm by 10mm, which serves as the standard for testing the impact energy specimens. The V-nock Charpy testing machine is used to test for the impact of energy in the experimental trials in the system. The testing machine and the experimental trials specimen are shown in Fig. 1b. The experimental trial results of the specimen are shown in Table 2.

Table 1. %age Chemical composition of Mild steel base metal material's element of IS 2062

Material	C	SI	Mn	P	S	Al	Cr	Mo	Ni
IS 2062	0.150	0.160	0.870	0.015	0.016	0.031	-	-	-
ER 308L	0.03	0.57	1.76	0.021	0.008	-	19.52	0.75	10.02


(A) (B)

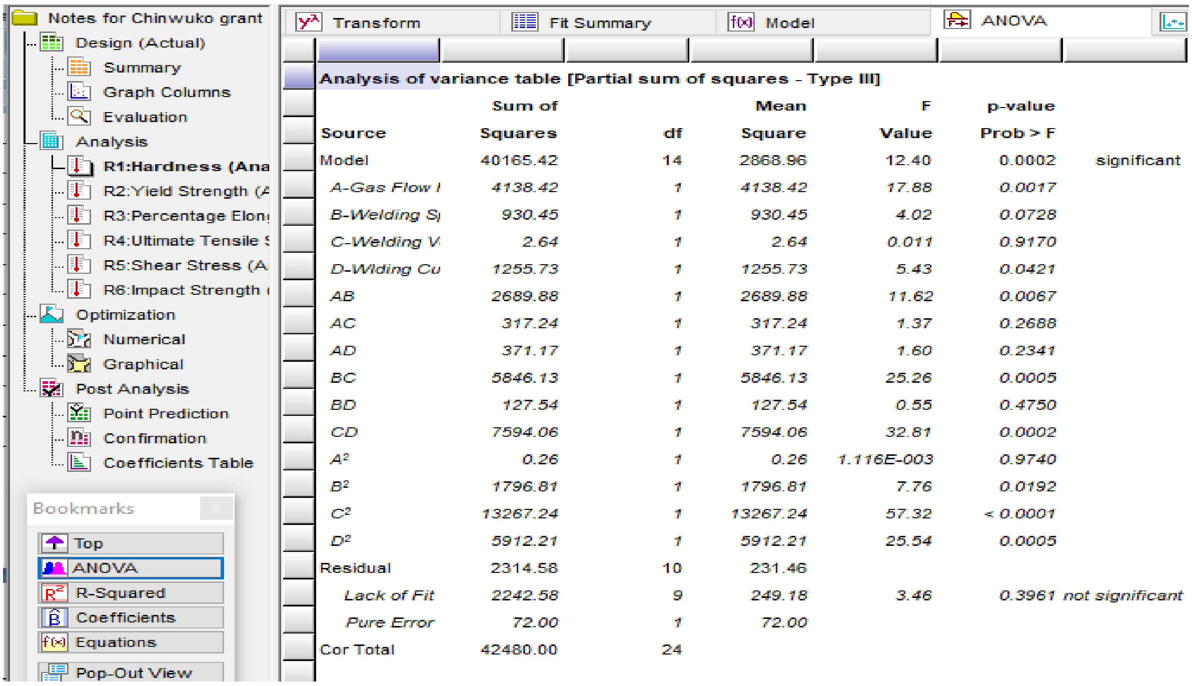
Fig. 1a(A-B). Sample of mild steel plate of IS2062 E-250 and its welding samples



(A) (B) (C)

(D)

Fig. 1b(A-D). Impact energy testing machine and its experimental specimen



Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	40165.42	14	2868.96	12.40	0.0002	significant
A-Gas Flow	*4138.42*	*1*	*4138.42*	*17.88*	*0.0017*	
B-Welding S	*930.45*	*1*	*930.45*	*4.02*	*0.0728*	
C-Welding V	*2.64*	*1*	*2.64*	*0.011*	*0.9170*	
D-Wlding Cu	*1255.73*	*1*	*1255.73*	*5.43*	*0.0421*	
AB	*2689.88*	*1*	*2689.88*	*11.62*	*0.0067*	
AC	*317.24*	*1*	*317.24*	*1.37*	*0.2688*	
AD	*371.17*	*1*	*371.17*	*1.60*	*0.2341*	
BC	*5846.13*	*1*	*5846.13*	*25.26*	*0.0005*	
BD	*127.54*	*1*	*127.54*	*0.55*	*0.4750*	
CD	*7594.06*	*1*	*7594.06*	*32.81*	*0.0002*	
A^2	*0.26*	*1*	*0.26*	*1.116E-003*	*0.9740*	
B^2	*1796.81*	*1*	*1796.81*	*7.76*	*0.0192*	
C^2	*13267.24*	*1*	*13267.24*	*57.32*	*< 0.0001*	
D^2	*5912.21*	*1*	*5912.21*	*25.54*	*0.0005*	
Residual	2314.58	10	231.46			
Lack of Fit	*2242.58*	*9*	*249.18*	*3.46*	*0.3961*	*not significant*
Pure Error	*72.00*	*1*	*72.00*			
Cor Total	42480.00	24				

Fig. 2. Analysis of variance for the hardness strength modeling

Table 2. The designed matrix input factors and the responses experimental results

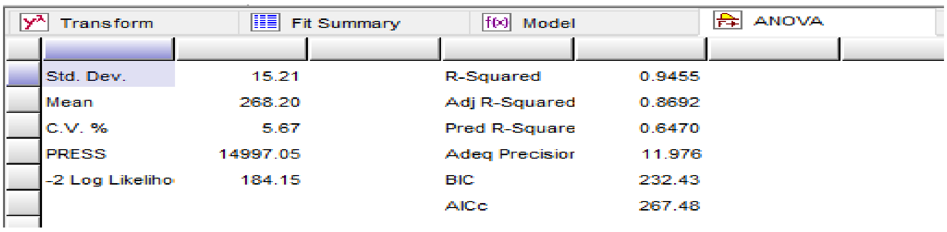
S/N	Control factors				Responses						
Runs	**Gas flow rate (L/min)**	**Welding speed (mm/s)**	**Welding voltage (V)**	**Welding current (A)**	**Hardness (BHN or HRB)**	**Yield strength (MPa)**	**Percentage elongation (%)**	**Tensile strength (MPa)**	**Shear stress (MPa)**	**Impact energy (J)**
1	13	110	20.5	210	263	280	28	480	361	91
2	10	130	18	230	305	310	15	520	382	110
3	10	130	23	230	274	356	25	503	387	70
4	16	90	18	230	250	162	35	443	394	113
5	16	90	23	230	348	270	28	524	301	71
6	13	110	20.5	190	230	282	26	335	305	82
7	10	90	23	190	204	202	21	436	390	90
8	13	130	20.5	210	234	224	27	397	344	89
9	16	90	23	190	277	230	24	432	303	90
10	10	90	18	190	226	237	23	354	365	83
11	13	130	23	210	320	294	26	435	392	82.5
12	10	90	18	230	206	219	28	528	335	96
13	13	110	20.5	210	251	242	22	440	321	91
14	13	110	18	210	341	312	21	456	382	107
15	16	130	23	190	237	349	33	422	335	101
16	13	110	20.5	230	208	248	22	485	349	92
17	10	90	23	230	299	289	26	523	320	81
18	16	110	20.5	210	293	297	28	472	302	107
19	10	110	20.5	210	239	282	23	468	307	84
20	16	130	18	190	311	372	24	411	412	115
21	16	130	23	230	286	341	27	516	360	92
22	10	130	23	190	221	295	29	440	401	93
23	16	110	18	230	293	303	25	474	417	118
24	16	90	18	190	284	271	31	410	405	85
25	10	130	18	190	305	312	20	398	393	76

4. RESULTS AND DISCUSSION

Table 2 shows the design matrix input parameter used and its experimental results of the twenty-five (25) experimental trials performed in this research work. The input process factors are gas flow rate, welding speed, welding voltage, and welding current. The output process responses are; Hardness strength, Yield Strength, Percentage Elongation, Ultimate Tensile Strength, Shear Stress, and Impact Energy of the weld bead geometry. The input and output parameters were analyzed statistically modeled and optimized. The results were revealed and discussed. The statistical analysis of the input and output parameters of the experiment was represented in Figs. 2 to 17.

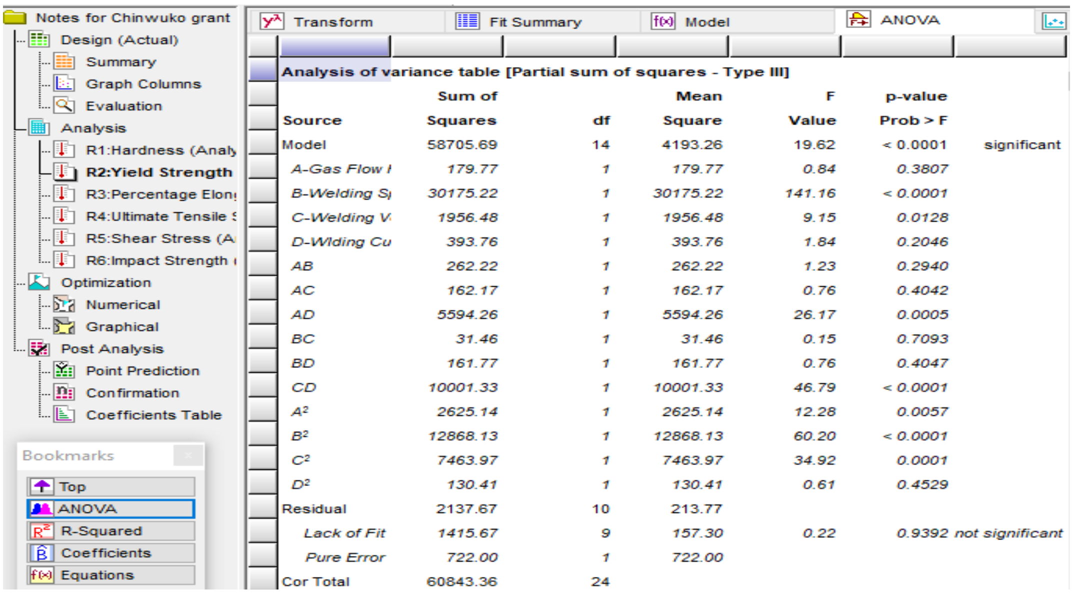
Fig. 2 is the analysis of variance for the hardness strength modeling which shows that the model developed is significant and fit to achieve an appropriate solution. The Model F-value of 12.40 implies the model is significant. There is only a 0.02% chance that an F-value this large could occur due to noise. The probability Values that are less than or equal to 0.0500 indicate model terms are significant. The probability Values that are greater than 0.0500 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model. The lack of fit F-value of 3.46 implies the lack of fit is not significant relative to the pure error. There is a 39.61% chance that a lack of fit F-value this large could occur due to noise. Non-significant lack of fit is good for the model to fit.

The model summary shows that the coefficient of determination for the factors and the response (R-Square) is 94.55%. This shows that 94.55 percent of the factors will be explained in the response parameter. The model summary also shows that the predicted R-Squared of 0.6470 and the adjusted R-Squared of 0.8692 are good percentage explanations and expectations of good experimental data. Adequate Precision is used to measure the signal-to-noise ratio. A ratio greater than 4 is desirable. Your ratio of 11.976 indicates an adequate signal. This model can be used to navigate the design space.



Std. Dev.	15.21	R-Squared	0.9455
Mean	268.20	Adj R-Squared	0.8692
C.V. %	5.67	Pred R-Square	0.6470
PRESS	14997.05	Adeq Precisior	11.976
-2 Log Likeliho	184.15	BIC	232.43
		AICc	267.48

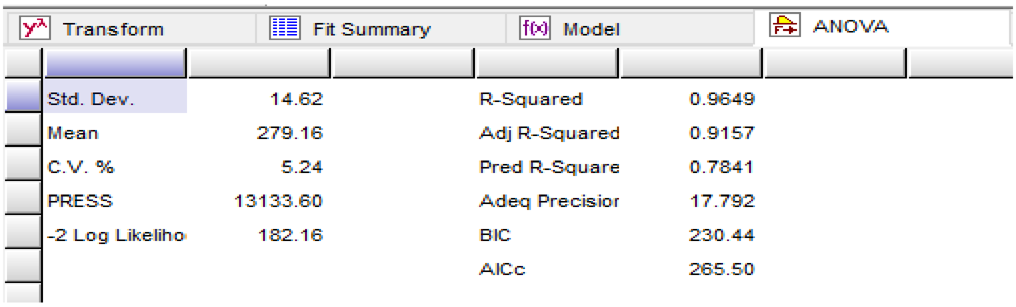
Fig. 3. Model summary for hardness strength test



Analysis of variance table [Partial sum of squares - Type III]

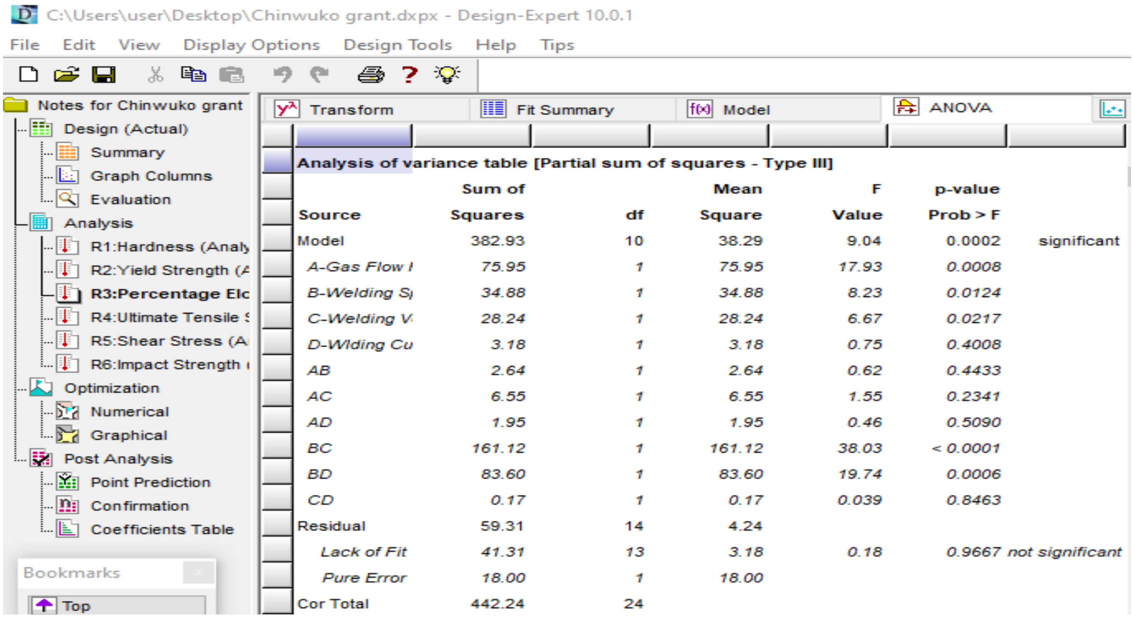
Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	58705.69	14	4193.26	19.62	< 0.0001	significant
A-Gas Flow I	*179.77*	*1*	*179.77*	*0.84*	*0.3807*	
B-Welding S	*30175.22*	*1*	*30175.22*	*141.16*	*< 0.0001*	
C-Welding V	*1956.48*	*1*	*1956.48*	*9.15*	*0.0128*	
D-Wlding Cu	*393.76*	*1*	*393.76*	*1.84*	*0.2046*	
AB	*262.22*	*1*	*262.22*	*1.23*	*0.2940*	
AC	*162.17*	*1*	*162.17*	*0.76*	*0.4042*	
AD	*5594.26*	*1*	*5594.26*	*26.17*	*0.0005*	
BC	*31.46*	*1*	*31.46*	*0.15*	*0.7093*	
BD	*161.77*	*1*	*161.77*	*0.76*	*0.4047*	
CD	*10001.33*	*1*	*10001.33*	*46.79*	*< 0.0001*	
A^2	*2625.14*	*1*	*2625.14*	*12.28*	*0.0057*	
B^2	*12868.13*	*1*	*12868.13*	*60.20*	*< 0.0001*	
C^2	*7463.97*	*1*	*7463.97*	*34.92*	*0.0001*	
D^2	*130.41*	*1*	*130.41*	*0.61*	*0.4529*	
Residual	2137.67	10	213.77			
Lack of Fit	*1415.67*	*9*	*157.30*	*0.22*	*0.9392*	*not significant*
Pure Error	*722.00*	*1*	*722.00*			
Cor Total	60843.36	24				

Fig. 4. Analysis of variance for the yield strength modeling



Std. Dev.	14.62	R-Squared	0.9649
Mean	279.16	Adj R-Squared	0.9157
C.V. %	5.24	Pred R-Square	0.7841
PRESS	13133.60	Adeq Precisior	17.792
-2 Log Likeliho	182.16	BIC	230.44
		AICc	265.50

Fig. 5. Model summary for yield strength test



Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	382.93	10	38.29	9.04	0.0002	significant
A-Gas Flow I	*75.95*	*1*	*75.95*	*17.93*	*0.0008*	
B-Welding S	*34.88*	*1*	*34.88*	*8.23*	*0.0124*	
C-Welding V	*28.24*	*1*	*28.24*	*6.67*	*0.0217*	
D-Wlding Cu	*3.18*	*1*	*3.18*	*0.75*	*0.4008*	
AB	*2.64*	*1*	*2.64*	*0.62*	*0.4433*	
AC	*6.55*	*1*	*6.55*	*1.55*	*0.2341*	
AD	*1.95*	*1*	*1.95*	*0.46*	*0.5090*	
BC	*161.12*	*1*	*161.12*	*38.03*	*< 0.0001*	
BD	*83.60*	*1*	*83.60*	*19.74*	*0.0006*	
CD	*0.17*	*1*	*0.17*	*0.039*	*0.8463*	
Residual	59.31	14	4.24			
Lack of Fit	*41.31*	*13*	*3.18*	*0.18*	*0.9667*	*not significant*
Pure Error	*18.00*	*1*	*18.00*			
Cor Total	442.24	24				

Fig. 6. Analysis of variance for the percentage elongation modeling

Fig. 4 is the analysis of variance for the yield strength modeling which shows that the model developed is significant and fit to achieve an appropriate solution. The Model F-value of 19.62 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. The probability Values that are less than or equal to 0.0500 indicate model terms are significant. The probability Values that are greater than 0.0500 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model. The lack of fit F-value of 0.22 implies the lack of fit is not significant relative to the pure error. There is a 93.92% chance that a lack of fit F-value this large could occur due to noise. Non-significant lack of fit is good for the model to fit.

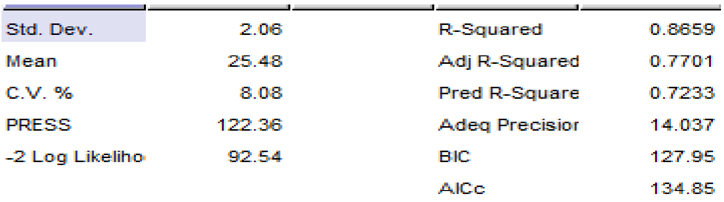
Fig. 5 reveals the yield strength model summary analysis which shows that the coefficient of determination for the factors and the response (R-Square) is 96.49%. This shows that 94.55 percent of the factors will be explained in the response parameter. The model summary also shows that the predicted R-Squared of 0.7841 and the adjusted R-Squared of 0.9157 are good percentage explanations and expectations of good experimental data. Adequate Precision is used to measure the signal-to-noise ratio. A ratio greater than 4 is desirable. Your ratio of 17.792 indicates an adequate signal. This model can be used to navigate the design space.

Fig. 6 is the analysis of variance for the percentage elongation modeling which shows that the model developed is significant and fit to achieve an improved solution. The Model F-value of 9.04 implies the model is significant. There is only a 0.02% chance that an F-value this large could occur due to noise. The probability Values that are less than or equal to 0.0500 indicate model terms are significant. The probability Values that are greater than 0.0500 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model. The lack of fit F-value of 0.18 implies the lack of fit is not significant relative to the pure error. There is a 96.67% % chance that a lack of fit F-value this large could occur due to noise. Non-significant lack of fit is good for the model to fit.

Fig. 7 reveals the percentage elongation model summary analysis which shows that the coefficient of determination for the factors and the response (R-Square) is 96.49%. This shows that 86.59 percent of the factors will be explained in the response parameter. The model summary also shows that the predicted R-Squared of 0.7233 and the adjusted R-Squared of 0. 7701 are good percentage explanations and expectations of good experimental data. Adequate Precision is used to measure the signal-to-noise ratio. A ratio greater than 4 is desirable. Your ratio of 14.037 indicates an adequate signal. This model can be used to navigate the design space.

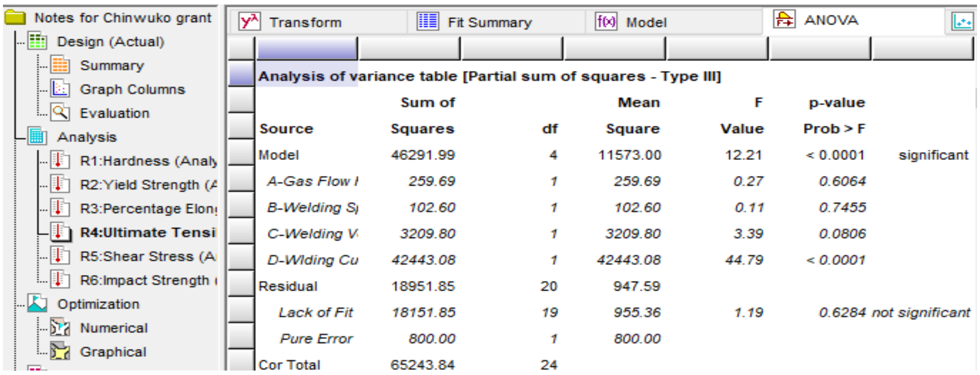
Fig. 8 is the analysis of variance for the ultimate tensile strength modeling which shows that the model developed is significant and fit to achieve an improved solution. The Model F-value of 12.21 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. The probability Values that are less than or equal to 0.0500 indicate model terms are significant. The probability Values that are greater than 0.0500 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model. The lack of fit F-value of 0.18 implies the lack of fit is not significant relative to the pure error. There is a 62.84% chance that a lack of fit F-value this large could occur due to noise. Non-significant lack of fit is good for the model to fit.

Fig. 9 reveals the ultimate tensile strength model summary analysis which shows that the coefficient of determination for the factors and the response (R-Square) is 70.95%. This shows that 70.95 percent of the factors will be explained in the response parameter. The model summary also shows that the predicted R-Squared of 0.5646 and the adjusted R-Squared of 0.6514 are good percentage explanations and expectations of good experimental data. Adequate Precision is used to measure the signal-to-noise ratio. A ratio greater than 4 is desirable. The ratio of 9.933 indicates an adequate signal. This model can be used to navigate the design space.



Std. Dev.	2.06	R-Squared	0.8659
Mean	25.48	Adj R-Squared	0.7701
C.V. %	8.08	Pred R-Square	0.7233
PRESS	122.36	Adeq Precisior	14.037
-2 Log Likeliho	92.54	BIC	127.95
		AICc	134.85

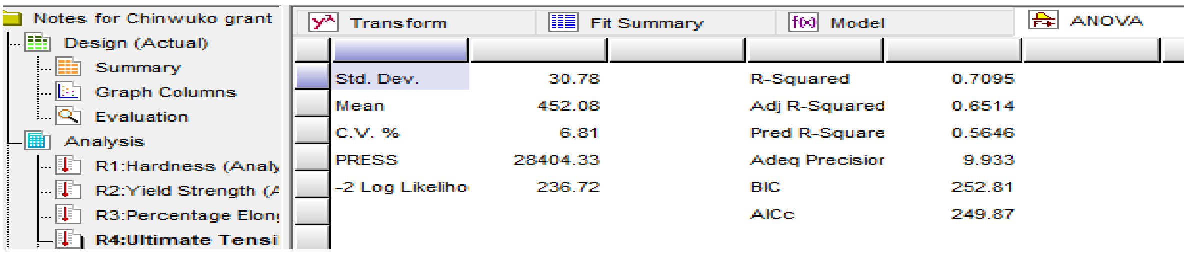
Fig. 7. Model summary for percentage elongation analysis



Analysis of variance table [Partial sum of squares - Type III]

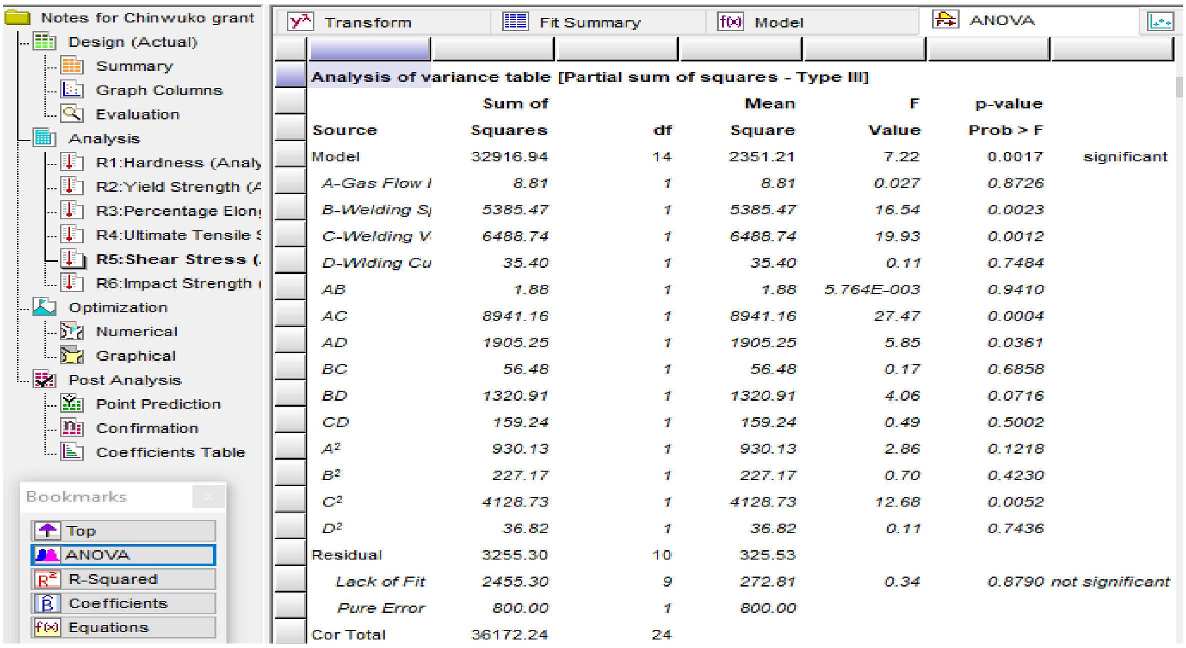
Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	46291.99	4	11573.00	12.21	< 0.0001	significant
A-Gas Flow I	*259.69*	*1*	*259.69*	*0.27*	*0.6064*	
B-Welding S	*102.60*	*1*	*102.60*	*0.11*	*0.7455*	
C-Welding V	*3209.80*	*1*	*3209.80*	*3.39*	*0.0806*	
D-Wlding Cu	*42443.08*	*1*	*42443.08*	*44.79*	*< 0.0001*	
Residual	18951.85	20	947.59			
Lack of Fit	*18151.85*	*19*	*955.36*	*1.19*	*0.6284*	*not significant*
Pure Error	*800.00*	*1*	*800.00*			
Cor Total	65243.84	24				

Fig. 8. Analysis of variance for the ultimate tensile strength modeling



Std. Dev.	30.78	R-Squared	0.7095
Mean	452.08	Adj R-Squared	0.6514
C.V. %	6.81	Pred R-Square	0.5646
PRESS	28404.33	Adeq Precisior	9.933
-2 Log Likeliho	236.72	BIC	252.81
		AICc	249.87

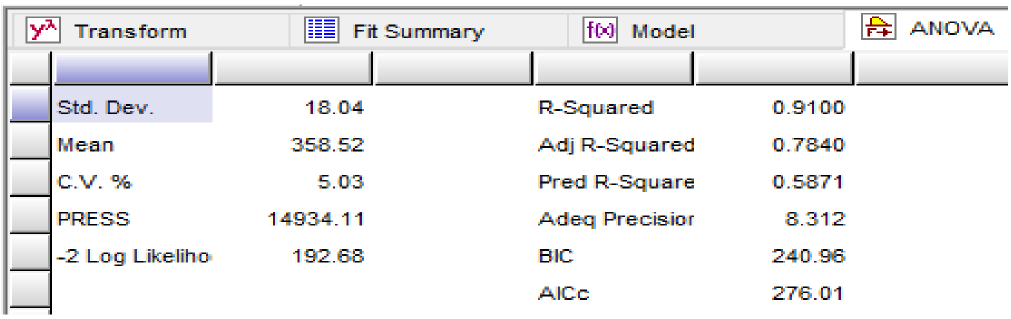
Fig. 9. Model summary for ultimate tensile strength test



Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	32916.94	14	2351.21	7.22	0.0017	significant
A-Gas Flow	*8.81*	*1*	*8.81*	*0.027*	*0.8726*	
B-Welding S	*5385.47*	*1*	*5385.47*	*16.54*	*0.0023*	
C-Welding V	*6488.74*	*1*	*6488.74*	*19.93*	*0.0012*	
D-Wlding Cu	*35.40*	*1*	*35.40*	*0.11*	*0.7484*	
AB	*1.88*	*1*	*1.88*	*5.764E-003*	*0.9410*	
AC	*8941.16*	*1*	*8941.16*	*27.47*	*0.0004*	
AD	*1905.25*	*1*	*1905.25*	*5.85*	*0.0361*	
BC	*56.48*	*1*	*56.48*	*0.17*	*0.6858*	
BD	*1320.91*	*1*	*1320.91*	*4.06*	*0.0716*	
CD	*159.24*	*1*	*159.24*	*0.49*	*0.5002*	
A^2	*930.13*	*1*	*930.13*	*2.86*	*0.1218*	
B^2	*227.17*	*1*	*227.17*	*0.70*	*0.4230*	
C^2	*4128.73*	*1*	*4128.73*	*12.68*	*0.0052*	
D^2	*36.82*	*1*	*36.82*	*0.11*	*0.7436*	
Residual	3255.30	10	325.53			
Lack of Fit	*2455.30*	*9*	*272.81*	*0.34*	*0.8790*	*not significant*
Pure Error	*800.00*	*1*	*800.00*			
Cor Total	36172.24	24				

Fig. 10. Analysis of variance for the shear stress modeling



Std. Dev.	18.04	R-Squared	0.9100
Mean	358.52	Adj R-Squared	0.7840
C.V. %	5.03	Pred R-Square	0.5871
PRESS	14934.11	Adeq Precisior	8.312
-2 Log Likeliho	192.68	BIC	240.96
		AICc	276.01

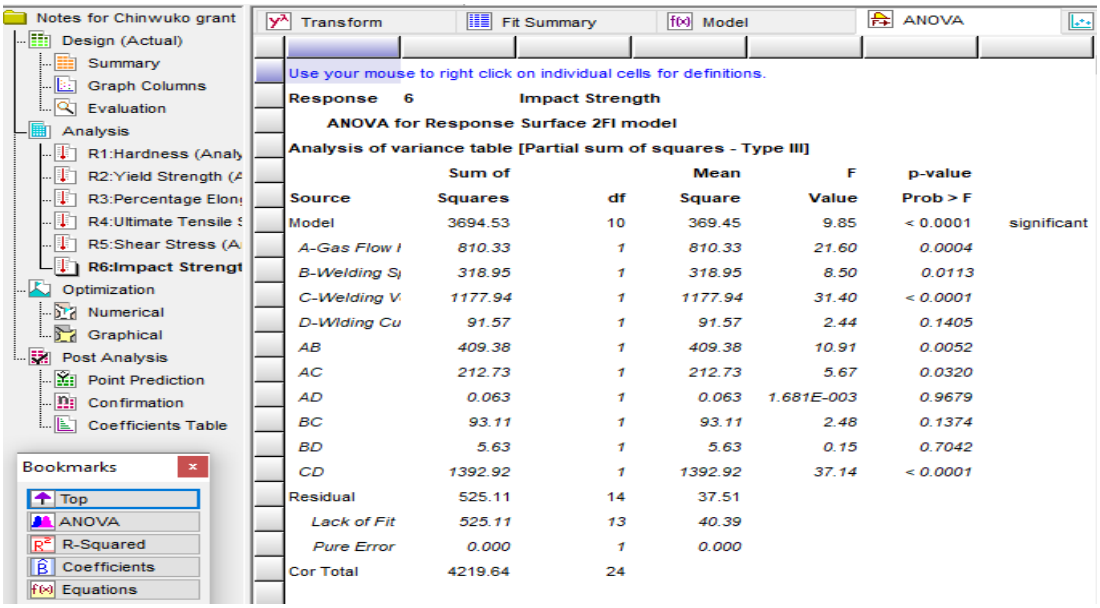
Fig. 11. Model summary for shear stress test

Fig. 10 is the analysis of variance for the shear stress modeling which shows that the model developed is significant and fit to achieve an improved solution. The Model F-value of 7.22 implies the model is significant. There is only a 0. 17% chance that an F-value this large could occur due to noise. The probability Values that are less than or equal to 0.0500 indicate model terms are significant. The probability Values that are greater than 0.0500 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model. The lack of fit F-value of 0.34 implies the lack of fit is not significant relative to the pure error. There is an 87.90% chance that a lack of fit F-value this large could occur due to noise. Non-significant lack of fit is good for the model to fit.

Fig. 11 reveals the shear stress model summary analysis which shows that the coefficient of determination for the factors and the response (R-Square) is 91.00%. This shows that 91.00 percent of the factors will be explained in the response parameter. The model summary also shows that the predicted R-Squared of 0.5871 and the adjusted R-Squared of 0.7840 are good percentage explanations and expectations of good experimental data. Adequate Precision is used to measure the signal-to-noise ratio. A ratio greater than 4 is desirable. The ratio of 8.312 indicates an adequate signal. This model can be used to navigate the design space.

Fig. 12 is the analysis of variance for the impact energy modeling which shows that the model developed is significant and fit to achieve an improved solution. The Model F-value of 9.85 implies the model is significant. There is only a 0. 01% chance that an F-value this large could occur due to noise. The probability Values that are less than or equal to 0.0500 indicate model terms are significant. The probability Values that are greater than 0.0500 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model.

Fig. 13 reveals the impact energy model summary analysis which shows that the coefficient of determination for the factors and the response (R-Square) is 87.56%. This shows that 87.56 percent of the factors will be explained in the response parameter. The model summary also shows that the predicted R-Squared of 0.4515 and the adjusted R-Squared of 0.7867 are good percentage explanations and expectations of good experimental data. Adequate Precision is used to measure the signal-to-noise ratio. A ratio greater than 4 is desirable. The ratio of 12.727 indicates an adequate signal. This model can be used to navigate the design space.



Use your mouse to right click on individual cells for definitions.

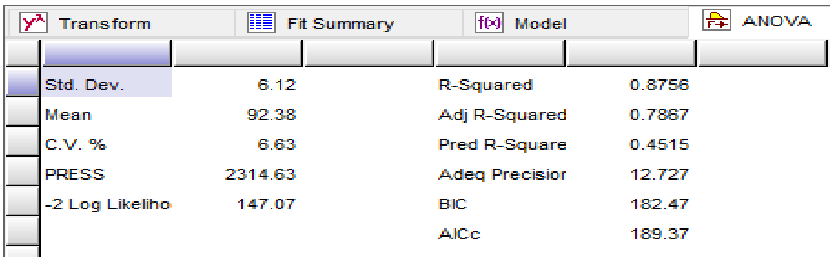
Response 6 Impact Strength

ANOVA for Response Surface 2FI model

Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	3694.53	10	369.45	9.85	< 0.0001	significant
A-Gas Flow I	*810.33*	*1*	*810.33*	*21.60*	*0.0004*	
B-Welding S	*318.95*	*1*	*318.95*	*8.50*	*0.0113*	
C-Welding V	*1177.94*	*1*	*1177.94*	*31.40*	*< 0.0001*	
D-Wlding Cu	*91.57*	*1*	*91.57*	*2.44*	*0.1405*	
AB	*409.38*	*1*	*409.38*	*10.91*	*0.0052*	
AC	*212.73*	*1*	*212.73*	*5.67*	*0.0320*	
AD	*0.063*	*1*	*0.063*	*1.681E-003*	*0.9679*	
BC	*93.11*	*1*	*93.11*	*2.48*	*0.1374*	
BD	*5.63*	*1*	*5.63*	*0.15*	*0.7042*	
CD	*1392.92*	*1*	*1392.92*	*37.14*	*< 0.0001*	
Residual	525.11	14	37.51			
Lack of Fit	*525.11*	*13*	*40.39*			
Pure Error	*0.000*	*1*	*0.000*			
Cor Total	4219.64	24				

Fig. 12. Analysis of variance for the impact of energy modeling



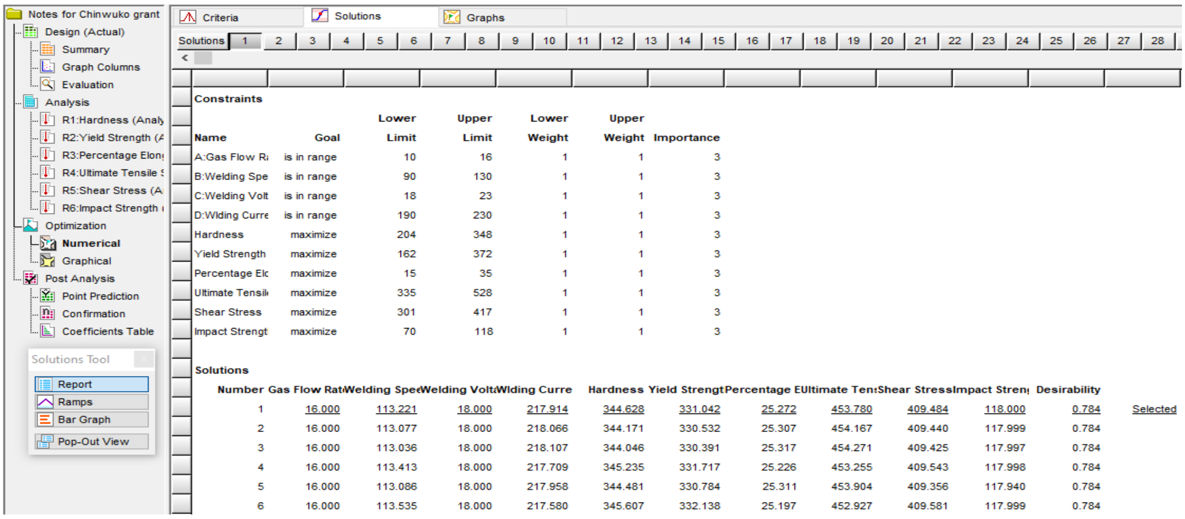
Std. Dev.	6.12	R-Squared	0.8756
Mean	92.38	Adj R-Squared	0.7867
C.V. %	6.63	Pred R-Square	0.4515
PRESS	2314.63	Adeq Precisior	12.727
-2 Log Likeliho	147.07	BIC	182.47
		AICc	189.37

Fig. 13. Model summary for impact energy

5. OPTIMIZATION SOLUTIONS

The report of the optimization shows that the iteration found six hundred and ninety-two (692) solutions. The optimization results show that the optimal solutions for input process factors are: a gas flow rate of 16.00m3/s, welding speed is 113.221m/s, welding voltage is 18.00V, and welding current is 217.914A. The optimization results for the response parameters are; 344.628MPa for Hardness strength, 331.042 MPa for Yield strength, 25.272% for percentage Elongation, 452.780 for ultimate tensile strength, and 409.484 MPa for shear stress, and 118.00 J for impact energy response. The overall desirability of the models developed to achieve the optimal solutions result is 78.41%.

The desirability plot shows the percentage desirability of the input process factors and the response parameters. The input process factors show that there is a hundred percent (100%) desirability of the average input process factors to achieve the desired goals. In the responses, the hardness strength test shows 97.66% desirability result, the yield strength test shows 80.50% desirability result, the percentage elongation response shows 51.36% desirability result, the ultimate tensile strength test shows 61.54% desirability result, the shear stress test shows 93.52% desirability result, and the impact energy response shows 100.00% desirability result. However, the average result of the response parameters is 78.41%.



Constraints

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A:Gas Flow Ra	is in range	10	16	1	1	3
B:Welding Spe	is in range	90	130	1	1	3
C:Welding Volt	is in range	18	23	1	1	3
D:Wlding Curre	is in range	190	230	1	1	3
Hardness	maximize	204	348	1	1	3
Yield Strength	maximize	162	372	1	1	3
Percentage Elc	maximize	15	35	1	1	3
Ultimate Tensil	maximize	335	528	1	1	3
Shear Stress	maximize	301	417	1	1	3
Impact Strengt	maximize	70	118	1	1	3

Solutions

Number	Gas Flow Rat	Welding Spe	Welding Volt	Wlding Curre	Hardness	Yield Strengt	Percentage E	Ultimate Ten	Shear Stress	Impact Stren	Desirability	
1	16.000	113.221	18.000	217.914	344.628	331.042	25.272	453.780	409.484	118.000	0.784	Selected
2	16.000	113.077	18.000	218.066	344.171	330.532	25.307	454.167	409.440	117.999	0.784	
3	16.000	113.036	18.000	218.107	344.046	330.391	25.317	454.271	409.425	117.997	0.784	
4	16.000	113.413	18.000	217.709	345.235	331.717	25.226	453.255	409.543	117.998	0.784	
5	16.000	113.086	18.000	217.958	344.481	330.784	25.311	453.904	409.356	117.940	0.784	
6	16.000	113.535	18.000	217.580	345.607	332.138	25.197	452.927	409.581	117.999	0.784	

Fig. 14. The report on the optimal solutions found

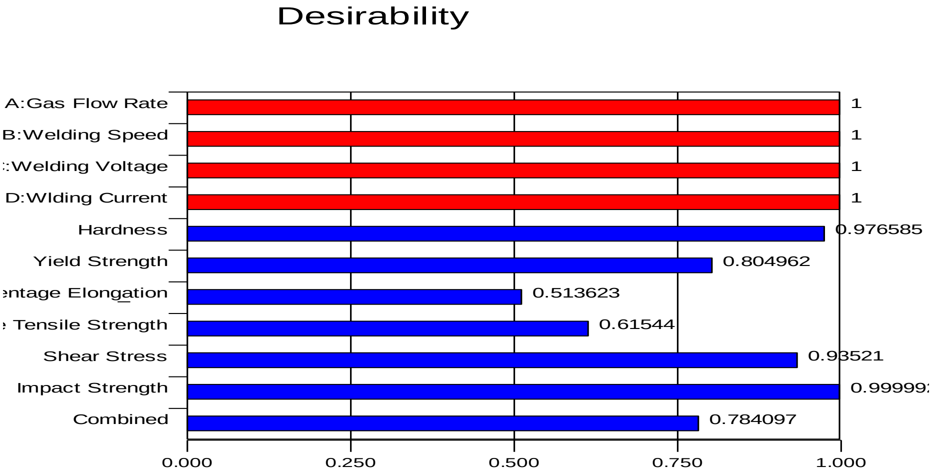


Fig. 15. The desirability plot for the optimal solutions

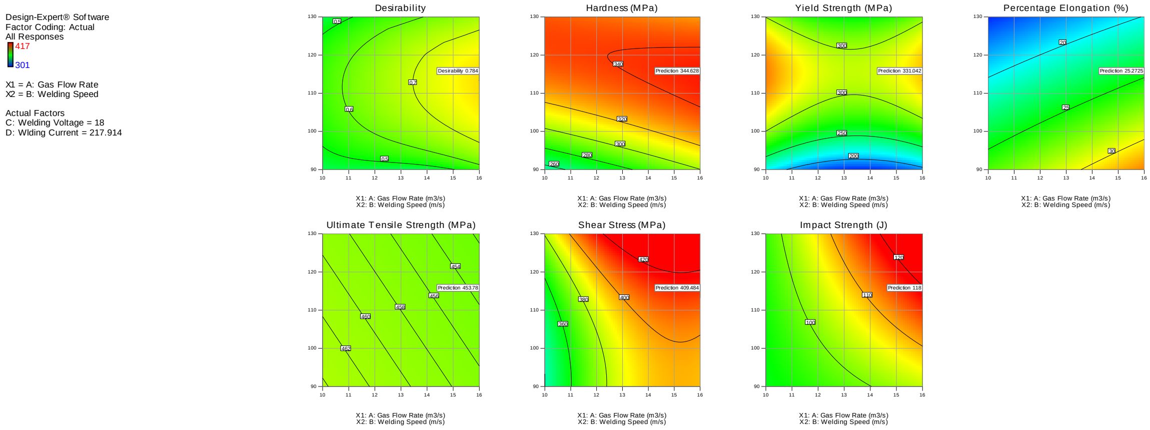


Fig. 16. Contour plots of the response parameters and desirability

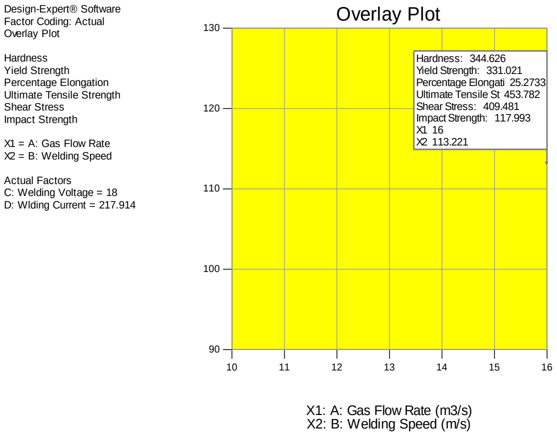


Fig. 17. The overlay plot of the responses and the input process factors

Fig. 16 shows the contour analysis and results of the response parameters and their optimal surface response solutions. The figure also reveals the optimal desirability solution on the contour surface plot. The desirability plot shows that where the optimal solution will occur in the base material (that is the mild steel metal) is at its average range. The hardness strength, shear stress, and impact energy responses will occur at the maximum of their experimental trial results. The yield strength, ultimate tensile strength, and percentage elongation response parameters show that their optimal solutions will occur at their average range on their experimental trial results.

Fig. 17 shows the overlay plot of the optimal solutions for the responses and the input factors. The responses show that the optimal solutions will occur at the pick of the selected experimental range for the gas flow rate, and welding speed. The result also shows that the welding current optimal solution for the responses will occur at the welding current average experimental range. Finally, the welding voltage optimal solution for the responses will occur at the welding voltage minimum selected experimental range. The optimal solution for the gas flow rate is 16.00m3/s, welding speed is 113.221m/s, welding voltage is 18.00V, and welding current is 217.914A. The optimization results for the response parameters are; 344.628MPa for Hardness strength, 331.042 MPa for Yield strength, 25.272% for percentage Elongation, 452.780 for ultimate tensile strength, and 409.484 MPa for shear stress, and 118.00 J for impact energy response.

6. CONCLUSION

In conclusion, the research has shown the optimal solutions of the input factors and the response parameters. The response surface optimization method results show that the optimal solutions for input process factors for the gas flow rate are 16.00m3/s, welding speed is

113.221m/s, welding voltage is 18.00V, and welding current is 217.914A. The optimization results for the response parameters are; 344.628MPa for Hardness strength, 331.042 MPa for Yield strength, 25.272% for percentage Elongation, 452.780 for ultimate tensile strength, and 409.484 MPa for shear stress, and 118.00 J for impact energy response. The overall desirability of the models developed to achieve the optimal solutions result is 78.41%. The research has revealed the appropriate optimal results for the mechanical properties of the optimization solutions for the IS 2062 mild steel material under study. The researchers recommend the results for industrial usage and decision-making in companies and the industrialization sectors.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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