RESPONSE SURFACE OPTIMIZATION OF SOME PROPERTIES OF PROCESS ANNEALED LOW CARBON STEEL

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Absract- In wire drawing process, the yield strength, tensile strength and impact toughness play major role in the structural reliability of the drawn wire. Low carbon steel wiresof 0.12wt% C are used for the manufacture of plain nails. Improved yield strength and impact toughness of the nails are often desire to avoid fracture failure andbuckling. In this study, polynomial modeling coupled with Response Surface Methodology was used to study the behavior of the tensile properties and impact toughness of cold drawn low carbon steel when annealed at various temperatures and soaking time. The Response Surface Methodology (RSM) was used to investigate the individual and interaction effect of annealing temperature and soaking time as independent variables on the yield strength, tensile strength and impact toughness properties of annealed cold drawn low carbon steel. The steel wire cold-drawn to 20% was annealed at various temperatures between 500oC-650oC for soaking time of between 10 minutes-60 minutes. The influence of the annealing temperature and soaking time on the yield strength, tensile strength and impact toughness were investigated by modeling the relationship using second order quadratic polynomials to develop the response surface plots and their respective contour plots. The RSM proposes models describing the influence of the annealing heat treatment parameters on the properties of the heat treated cold drawn wires. The model was able to account for the curvature of the response and the interaction of the independent variables in the response surface. The response surface methodology (RSM) was applied to optimize the annealing process parameters to attain the optimal values of the properties.The optimized values for the yield strength, tensile strength and impact toughness for the heat treated cold drawn wire were obtained as 678.90 MPa, 779.15 MPa and 42.65 J respectively. The optimization was achieved within the 95% confidence interval.

Index Terms-Cold drawn, steel, annealing, temperature, time, yield strength, tensile strength, impact toughness, optimization, RSM, model

1 INTRODUCTION

Various heat treatments such as annealing, normalizing, hardening, and tempering are used to alter the mechanical properties of steel. These properties may include the yield strength, ductility, tensile strength, hardness and impact strength of the steel. [1], [2], [3]. These are dependent on the steel microstructure which is altered during the deformation and heat treatment processing of the steel [4], [5], [6]. It is possible to influence considerably a complex of mechanical properties of steel by a suitable combination of size of previous cold deformation and parameters of annealing properties [7], [8], [9]. The annealing parameters have been investigated and found to have considerable influence on the properties of the low carbon steel [10], [11].The annealing process enables the design of desired microstructure by altering the annealing parameters such as the annealing temperature and soaking time [12], [13]. It is often desired to obtain a suitable combination of the annealing parameters for optimized properties of the materials. The material properties could be defined as functions of these annealing parameters for purpose of optimization. The effect of cold drawing and heat treatment on the microstructure and mechanical properties of low carbon steel wire have recently been explore [10], [14], [15] and it has become a concern to obtain suitable heat treatment parameters for optimized properties of steel.

Considerable attempts have been made to optimize heat treatment parameters. These include classical optimization technique [16], [17], evolutionary algorithm procedure [18] and artificial neural net-work combined with genetic algorithm [19].The optimization of the tensile properties of annealed cold drawn low carbon steel was attempted in [16] in which single variable technique was used to determine suitable annealing temperature and soaking time for optimized tensile properties of the annealed cold drawn low carbon steel. The technique considered keeping the temperature constant and varying the soaking time for each properties and in turn keeping the soaking time constant and varying the annealing temperature. It is possible in the single variable method to miss the global optimal of the property's value because the maximal value of one variable is usuallynot independent of the other one [20]. This technique did not consider the complex simultaneous influence of the annealing temperature and soaking time which could be of important influence on the optimized properties [16]. In this present study, the combined influence of the annealing temperature and soaking time of the heat treated low carbon steel is discussed. The yield strength, tensile strength and impact toughness of the annealed cold drawn steel are developed as functions of the annealing temperature and soaking time using the response surface methodology (RSM). It is desired to investigate how much of influence the annealing temperature and soaking time affects the property response of the cold drawn low carbon steel and to find the combination of these annealing parameters that will provide the optimal response of the properties.

The response surface methodology (RSM) is a statistical tool which describes the relationship between multi-independent variables with dependent variables referred to as the response variable [20]. RSM is used to investigate the optimal response of desired system parameters as a dependent variable of the system's experimental factors [21].
The Response Surface Analysis program fits a polynomial regression model with cross-product terms of variables that may be raised up to the third power. It calculates the minimum or maximum of the surface. The method is used for modeling and analyzing problems which response of interest is a function of the independent variables [22], [23]. The objective of the RSM is to optimize the desired response which is defined by the several independent variables[24].The response variable is a function of the independent variables and could be expressed as [25];

$$y = f(x_1, x_2, \ldots \ldots .x_k) + e$$

Where y is the response variable which is a dependent variable on x. x_i are the independent variables such that i = 1,2, 3 … . . k and e is the error in the response data. The error represents other source of variability not accounted for in the function, f. The function is usually expanded or approximated by various terms to generate polynomial equations.

2 METHODOLOGY

2.1 Heat Treatment Procedure

The material investigated was the low carbon steel with chemical composition as shown in Table 1. The carbon steel wire was cold drawn to 20% degree of deformation as obtained for the manufacture of 4 inches nails.A muffle furnace Gallenkomp® model SVL-1009 with voltage regulation of 220 V, 50Hz of temperature range 300°C – 1000°C was used to anneal the specimens at temperatures of 500oC, 550oC, 600oC and 650oC for soaking time ranging from 10 minutes to 60 minutes at interval of 10 minutes. Tensile tests were done at room temperature on an Instron® 3369 testing machine equipped with an electro-mechanical sensor for control of tensile strain in the active zone of the specimens in the load range up to 50 kN. The yield strength and tensile strength of the specimens were obtained from the tensile tests.

The relative toughness of the annealed specimen at the different soaking time was determined from Charpy impact test. For reproducibility, tests were carried out using five samples for each soaking time at each annealing temperature and the mean measurement were taken of the data with minimum measured standard error.

TABLE1
Chemical composition of the as-received steel wire material (wt. %)

C	Si	Mn	P	Fe
0.12	0.18	0.14	0.7	98.86

2.2 Response Surface Modeling Technique

The behavior of the yield strength $\sigma_{Y,}$ tensile strength $\sigma_{T,}$ and impact toughness $E_{ImT,}$ as obtained in the experimental data were modeled as functions of the annealing temperature and soaking time using the Response Surface Methodology (RSM). The response surface methodology is obtained from the design expert software version 7.0.0. Response surface methodology usually aim at determining the optimum settings for the variables and to see how the variables perform over the whole experimental domain, including any interactions such as the simultaneous influence of the annealing parameters on the properties of the annealed low carbon steel. The annealing temperature and soaking time were taking as two independent variables which determinethe response of the yield strength $\sigma_{Y,}$ tensile strength $\sigma_{T,}$ and impact toughness $E_{ImT,}$ of the steel to the annealing heat treatment parameters. The experimental design and statistical analysis were performed according to the response surface analysis method using Design Expert 7.0.0 software. Historical data obtained from the experiments was employed to study the combined effect of the annealing temperature (x_1) and soaking time (x_2). The dependent variables (y) measured were the steel yield strength $\sigma_{Y,}$, tensile strength σ_{T}, and impact toughness $E_{ImT,}$ of the annealed cold drawn wire.

These dependent variables were expressed individually as a function of the independent variables known as response function.

A cubicorder three dimensional surface model was chosen to describe the relationship between each of the propertiesy, and the two independent variables (annealing temperature; x_1, and soaking time; x_2). The model was able to account for the curvature of the response and the interaction of the independent variables in the response surface. The data point $\left(y, x_i, x_j\right)$ defines a curved surface in 3D spacerepresented by equation (1). The polynomial expression has been widely applied studies of optimization using the response surface methodology [21], [25], [26].

$$y = \beta_0 + \sum_{j=1}^{q} \beta_j x_j + \sum_{j=1}^{q} \beta_{jj} x_j^2 + + \sum_{j=1}^{q} \beta_{jj} x_j^3 + \sum_{i<j} \sum \beta_{ij} x_i x_j + e \quad (1)$$

The parameters $\beta_i$are constant coefficients known as the regression coefficients. These coefficients measure the expected change in the response y per unit increase in xi when the xjis held constant and vice versa andare established by regression analysis in the RSM programme. $\sum \beta_j x_j$is the main effect, $\sum \beta_{jj} x_j^2$ and $\sum \beta_{jj} x_j^3$ are the curvature, $\sum_{i<j} \sum \beta_{ij} x_i x_j$is the interaction and e is the error. All the coefficients were obtained by the use of the Design Expert software package. The student t-test and p-values were used to determine the significance of each coefficientas described in [22].The validity of the models wasverified by using the significance test of the regression of F-test which compares the variance of the regression with the residual variance.

3 RESULTS AND DISCUSSION

3.1 Influence of the Annealing Parameters on the Properties of the Steel

The results obtained from the tensile test and Charpy impact test experiments were used to describe the behavioral pattern of the yield strength $\sigma_{Y,}$ tensile strength $\sigma_{T,}$ and impact toughness $E_{ImT,}$ properties with the annealing temperature and soaking time as shown in Fig. 1,2,3. The figures expose the influence of the annealing temperature and soaking time on each of the properties.Improve in the yield strength is observed for the annealing temperature of 500ºC and 550ºC between the soaking time of 10minutes and 30 minutes after which the rate at which the yield strength increases for the treated samples reduces with increasing temperature of annealing for all the degrees of cold drawn deformation. The impact toughness was also observed to improve considerably when annealed at temperature between 500ºC and 650ºC. The tensile strength also improved between soaking time of 10 minutes and 25 minutes when annealed between 500ºC and about 530ºC.

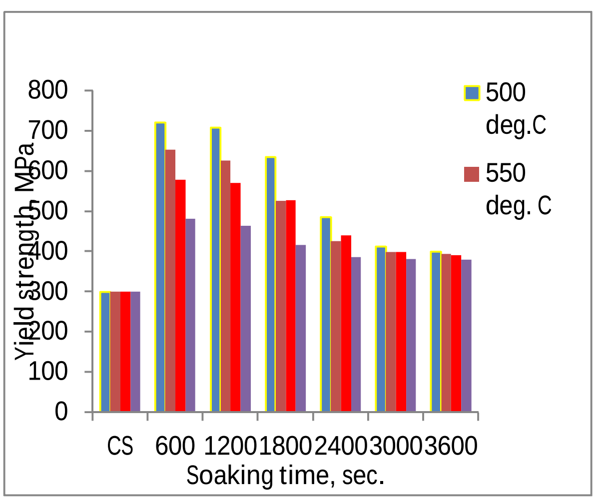
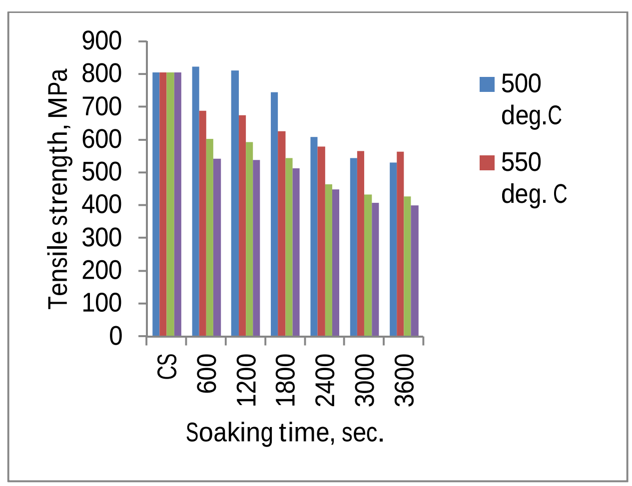


Fig.1. Yield strength response of annealed 20% cold drawn 0.12wt% C.



Fiq.2. Tensile strength response of annealed 20% cold drawn 0.12wt% C.

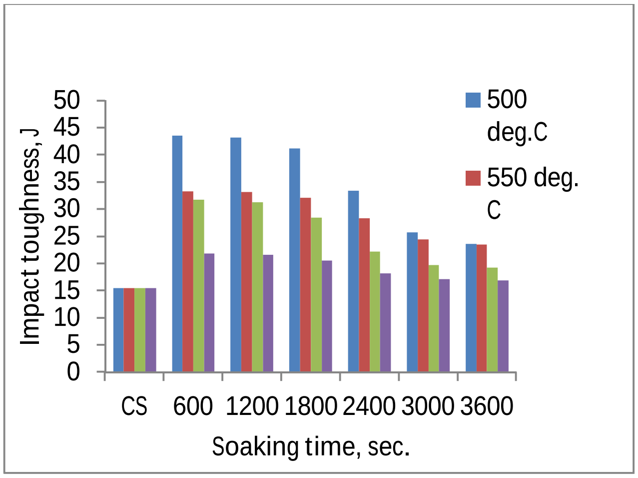


Fig.3.Impact toughness response of annealed 20% cold drawn 0.12wt% C

3.2 Response Surfaces Analysis

The actual design by the experimentation was obtained as shown in Table 2.The table shows the dependency of the yield strength, tensile strength and impact toughness on the annealing temperature and soaking time. The data were populated in the RSM actual-design value frame for 24 observations as obtained from Table 2. Tables 3,4,5shows the results of the model fit summary for the three properties under consideration as analyzed using the RSM. The results suggest cubic order polynomials for the description of the properties relationship with the annealing parameters. These are obtained by focusing on the models that maximizes the adjusted and predicted R-square values for each of the property and the lowest level of uncertainty. The cubic order model compared to the other models has the lowest standard deviation, higher R^2values and low predicted residual sum of squares for the three properties indicating that the cubic model is the most suitable for describing each of the steel property relationship with the annealing parameters.

TABLE2
Actual Experimental data as obtained from the tensile test and impact test

Yield Strength (MPa) of annealed 20% cold drawn steel												
Soaking Time (min.)	Annealing Temperature (deg. C)											
	500 deg.C			550 deg.C			600 deg.C			650 deg.C		
	σ_y	σ_T	E_{ImT}	σ_y	σ_T	E_{ImT}	σ_y	σ_T	E_{ImT}	σ_y	σ_T	E_{ImT}
10	720.92	823.77	43.56	653.01	688.04	33.31	578.11	603.26	31.79	482.38	542.89	21.88
20	707.66	811.71	43.24	626.3	675.22	33.15	570.4	593.34	31.27	463.87	538.6	21.67
30	635.56	746.16	41.19	525.81	627	32.13	528.48	544.44	28.46	415.81	513.43	20.56
40	485.13	609.4	33.46	425.32	578.78	28.32	441.03	463.84	22.21	386.66	448.09	18.25
50	413.02	543.84	25.72	398.61	565.96	24.5	399.11	432.79	19.8	380.75	408.45	17.14
60	399.77	531.79	23.66	394.51	563.99	23.48	391.4	427.51	19.28	379.9	400.41	16.93

TABLE 3.
Model Summary Statistics for Yield strength of annealed 20% cold drawn low carbon steel

Source	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	45.99	0.842	0.8269	0.7818	61327.93	
2FI	29.94	0.9362	0.9266	0.9096	25420.27	
Quadratic	30.24	0.9414	0.9252	0.8945	29650.78	
Cubic	18.88	0.9822	0.9708	0.9321	19070.5	Suggested

TABLE 4.
Model Summary Statistics for Yield strength of annealed 20% cold drawn low carbon steel

Source	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	39.00	0.8980	0.8883	0.8611	43528.20	
2FI	34.92	0.9222	0.9105	0.8922	33758.69	
Quadratic	35.95	0.9258	0.9051	0.8724	39959.06	
Cubic	22.63	0.9771	0.9624	0.9303	21842.35	Suggested

TABLE 5.
Model Summary Statistics for Yield strength of annealed 20% cold drawn low carbon steel

Source	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	2.81	0.8868	0.8760	0.8395	235.15	
2FI	2.08	0.9409	0.9321	0.9164	122.49	
Quadratic	2.11	0.9451	0.9299	0.9051	139.09	
Cubic	1.65	0.9739635	0.9572	0.9240	111.38	Suggested

The ANOVA for the response surface cubic model of the yield strength, tensile strength and impact toughness are as shown in Tables 6,7,8 respectively with estimated values of the regression coefficients. The F-values of 86.01, 63.93 and 58.19 respectively for the yield strength, tensile strength and impact toughness with p-values < 0.0001 implies that the models are significant.This means that there is only 0.01% chance that the model F-values as large as obtained could occur due to noise.

The model terms with p-values less than 0.05 are considered to be significant and influence the responses considerably. The smaller values of the p-values suggest that there is curvature in the response surface. This is in line with rejecting the hypothesis that a particular regression coefficient does not influence the property response. The most significant effect on the yield strength, were the soaking time (x_2) main effect with F-value = 139.22 and the interaction term $x_1x_2$with F-value = 74.25 both terms having p-value < 0.0001 which is followed by the cubic curvature term of the soaking time $x_2^3$with p = 0.0002 and the curvature term for annealing temperature x_1^3 with p = 0.0278. This implies that the soaking time has much more influence on the yield strength of the annealed 20% cold drawn steel. The other model terms with p-values greater than 0.05 indicates that the terms are not significant. In view of this the x_1, x_1^2, x_2^2, $x_1^2x_2$ and $x_1x_2^2$ terms does not have much influence on the yield strength of the steel. Similar evaluation for the tensile strength indicates that the model terms x_2, x_1, x_2^3, x_1x_2, $x_1^2x_2$ and x_1^3 are significant. Also for the impact toughness, x_1, x_2, x_1x_2 *and* x_2^3 are significant model terms.

The determination coefficient R^2 values of 98.22% for the yield strength response model, 97.71% for the tensile strength response model, and 97.4% for the impact toughness response model gives the confidence that the response models are good fits of the experiment data. The satisfactory correlation between the experimental and predicted values is also evident as shown in Fig. 4,5,6in which the plotted points are observed to cluster around the fit line as shown.

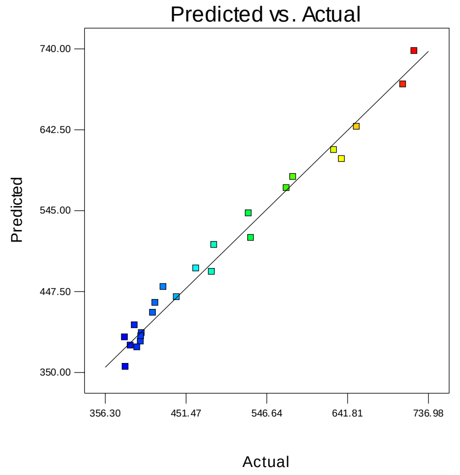


Fig. 4. Parity plot for yield strength experiment and predicted values

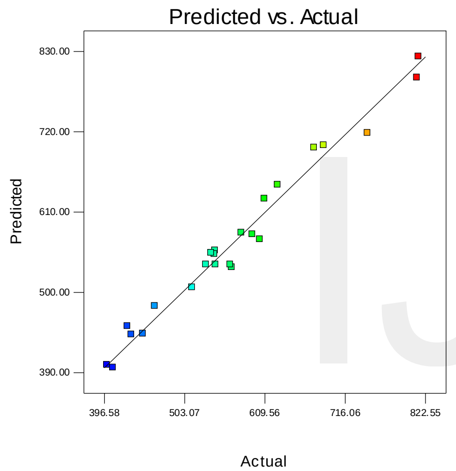


Fig. 5. Parity plot for tensile strength experiment and predicted values

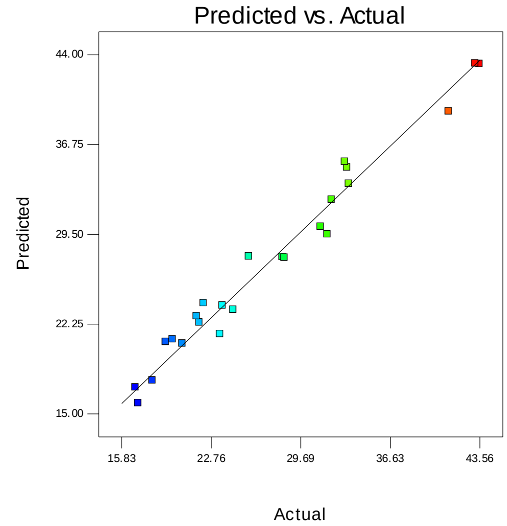


Fig. 6. Parity plot for impact toughness experiment and predicted values

TABLE 6
ANOVA for Yield Strength Response Surface of Annealed 20% cold drawn Low carbon Steel

Source	Coefficient Estimate	Standard Error	F-Value	p-Value Prob > F
Model			86.01064	< 0.0001
x_1	-110.06162	19.38	1.842086	0.1962
x_2	13.7396904	17.35	139.2154	< 0.0001
x_1x_2	-0.0333862	7.57	74.25303	< 0.0001
x_1^2	0.1917698	8.67	0.429911	0.5227
x_2^2	-0.6677169	9.66	3.691416	0.0753
$x_1^2x_2$	5.1406E-05	12.7	0.324179	0.5781
$x_1x_2^2$	0.00012946	12.96	0.219327	0.6468
x_1^3	-0.0001128	19.39	6.020693	0.0278
x_2^3	0.00593301	18.33	25.58406	0.0002
Intercept	21880.7236	7.64		

Std. Dev.	18.88	R-Squared	0.9822
Mean	491.81	Adj R-Squared	0.9708
C.V. %	3.84	Pred R-Squared	0.9321
PRESS	19070.5	Adeq Precision	31.229

TABLE 7
ANOVA for Tensile strength Response Surface of Annealed 20% cold drawn Low carbon Steel

Source	Coefficient Estimate	Standard Error	F-Value	p-Value Prob > F
Model			63.93288	< 0.0001
x_1	135.457714	23.46998	49.00229	< 0.0001
x_2	-101.287608	21.00812	52.13627	< 0.0001
x_1x_2	0.377507	9.168818	13.13532	0.0028
x_1^2	-0.253823	10.5042	1.660238	0.2185
x_2^2	-0.533271	11.69736	0.152713	0.7018
$x_1^2x_2$	-0.000309	15.37657	7.981598	0.0135
$x_1x_2^2$	-0.000065	15.69365	0.03735	0.8495
x_1^3	0.000155	23.48811	7.731271	0.0147
x_2^3	0.005503	22.19671	15.00455	0.0017
Intercept	-22852.639	9.25		

Std. Dev.	22.87	R-Squared	0.9762
Mean	569.70	Adj R-Squared	0.9610
C.V. %	4.01	Pred R-Squared	0.9267
PRESS	22610.86	Adeq Precision	28.8535

TABLE 8
ANOVA for Impact Toughness Response Surface of Annealed 20% cold drawn Low carbon Steel

Source	Coefficient Estimate	Standard Error	F-Value	p-Value Prob > F
Model			58.18972	< 0.0001
x_1	-6.508333	1.693925	12.95776	0.0029
x_2	-0.313075	1.516243	47.98697	< 0.0001
x_1x_2	0.005136	0.661751	29.08962	< 0.0001
x_1^2	0.010971	0.758132	0.00296	0.9574
x_2^2	-0.058858	0.844247	2.247354	0.1561
$x_1^2x_2$	-0.000005	1.109791	0.439904	0.5179
$x_1x_2^2$	0.000040	1.132676	2.714871	0.1217
x_1^3	-0.000006	1.695234	2.425206	0.1417
x_2^3	0.000323	1.602028	9.939209	0.0071
Intercept	1331.0898	0.67		

Std. Dev.	1.65	R-Squared	0.9740
Mean	27.29	Adj R-Squared	0.9572
C.V. %	6.05	Pred R-Squared	0.9240
PRESS	111.38	Adeq Precision	25.7498

The normal probability of the properties is shown in Fig.7,8,9. It could be observed that the residuals tend to aligned with the normal distribution assumptions as defined by the straight line. This implies that the errors are normally distributed. The models could therefore be considered useful for information extraction on the experiments. The signal to noise ratios for the three models describing the yield strength surface response, the tensile strength surface response and the impact toughness surface response indicates adequate signals having been determined as shown on the tables as 31.2285, 28.8535 and 25.7498 respectively. It is required by standard of the RSM model that this ratio greater than 4 is desirable [27]. These models can therefore be used to navigate the design space for the three responses.

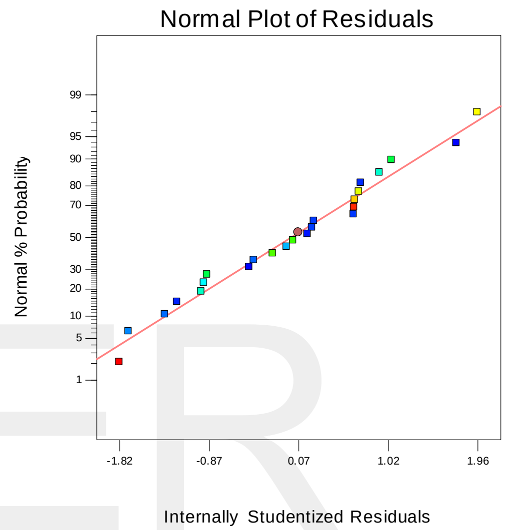


Fig.7. Normal distribution plot for error analysis of yield strength response model

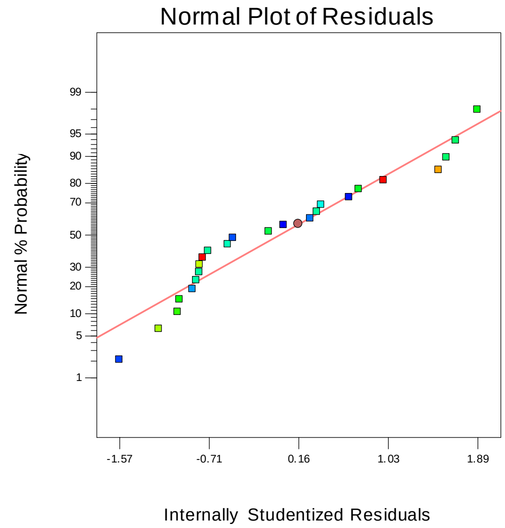


Figure 8. Normal distribution plot for error analysis of tensile strength response model

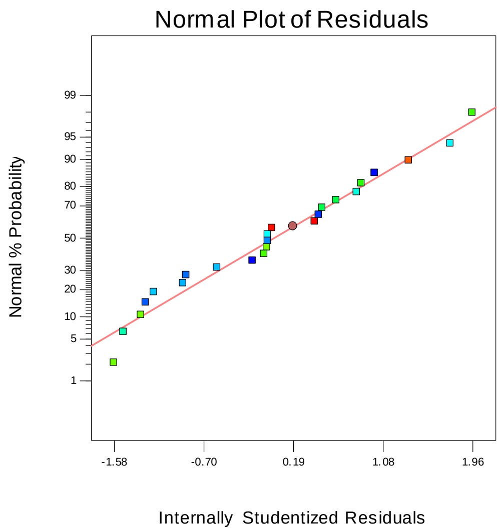


Fig. 9. Normal distribution plot for error analysis of tensile strength response model

The model equations arethus obtained as stated in equations (2)-(4). The insignificant model parameters are eliminated from the model expression.

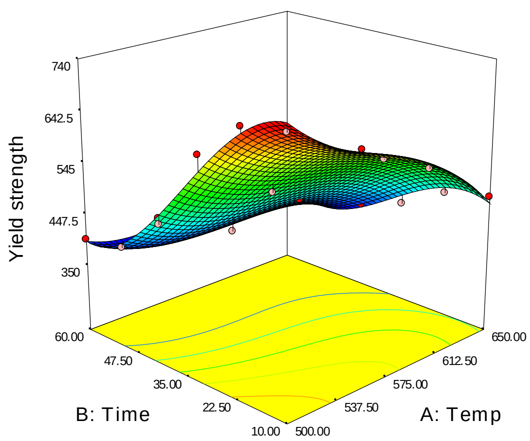
$$\sigma_y = 5.93(10^{-3})x_2^3 - 1.13(10^{-4})x_1^3 - 0.0334x_2x_1 + 13.74x_2 - 21880.72 \quad (2)$$

$$\sigma_T = 0.0055x_2^3 + 0.00015x_1^3 - 0.00031x_1^2x_2 + 0.3775x_1x_2 + 135.46x_1 - 101.29x_2 - 22852.64 \quad (3)$$

$$E_{ImT} = 0.000323x_2^3 + 0.00514x_1x_2 - 0.313x_2 - 6.508x_1 + 1331.09 \quad (4)$$

These models could be used to predict the listed properties of the steel within the limits of the experiment factors.

The surface plots and contour plots developed for the models of equations (2),(3),(4) are presented in Fig.10,11,12. The plots show the combined influence of the annealing parameters on the yield strength, tensile strength and impact toughness of the annealed cold drawn steel wire respectively. Time shows a strong positive effect on the yield strength and impact toughness of the steel. A more definite slope to lower time, indicating shorter soaking times are better. Both the annealing temperature and soaking time has equal effect on the tensile strength of the steel as shown on the surface plot of Fig.11a. The maximum achievableresponses of the properties are well exposed on the contour plots. It is clear from the plots that the yield strength, tensile strength and impact toughness of the annealed drawn steel decreases with increasing annealing temperature and soaking time indicating that maximum values of these properties could be obtained at lower annealing temperature and soaking time with considerable improvement of the yield strength of the steel wire to avoid fracture failure of the wire resulting from cold drawing process thereby improving the steel wire ductility. The independent influence of the annealing parameters is obtained on the surface plots. It is observed that the soaking time has greater influence on the three properties responses especially at lower soaking time as demonstrated by the steepness of the surfacesat this soaking time range.This influence is well exposed in the contour plotsfor the three properties.The improved yield strength is good for the steel wire which tends to prevent fracture failure of the steel wire when subjected to impact load. It is also desired that the steel does not fail by buckling. The yield strength therefore needed be maximized for the application. The surface and contour plots for the tensile strength response as shown in Fig.8 shows that maximum tensile strength could be obtained at lower annealing temperature and soaking time. However it is observed that global minimum exist in the tensile surface response plot as conspicuously shown in the contour plot of Figure 8b. This observation is also made on the surface plot and contour plot for the impact toughness property as shown in Fig.12. The implication is that the influence of the annealing parameters on the three properties should be considered simultaneously for a global emergence of optimal annealing parameters for improved properties of the cold drawn wire.



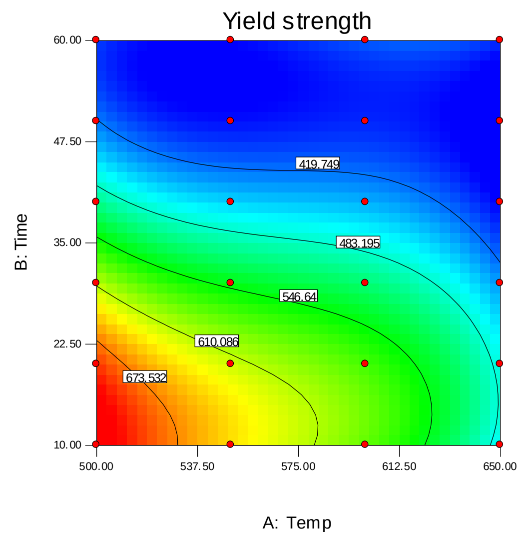
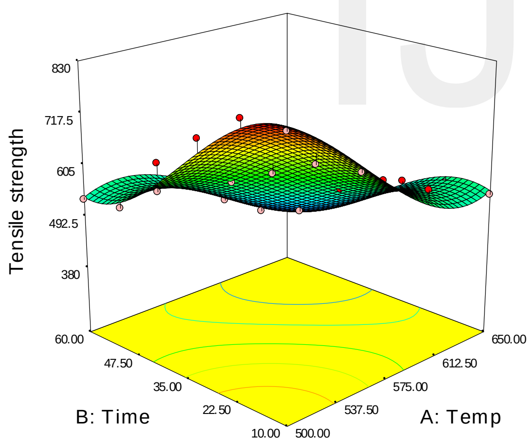


Fig.10. (a) 3D plot for yield strength response (b) Contour plot for yield strength response



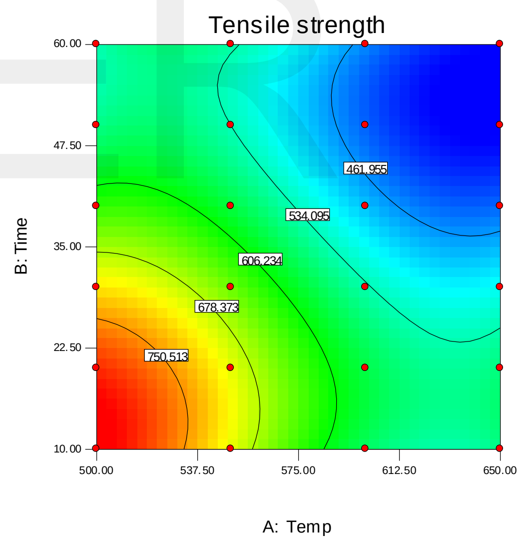
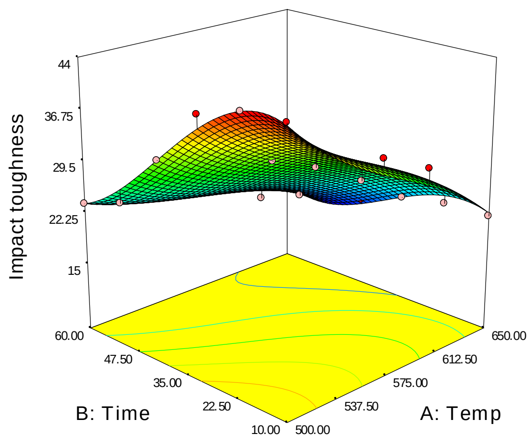


Fig. 11. (a) 3D plot for yield strength response (b) Contour plot for yield strength response



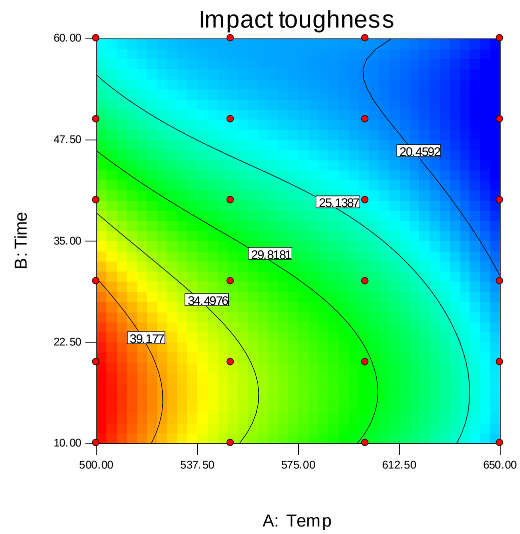


Figure12 (a) 3D plot for yield strength response

(b) Contour plot for yield strength response

The influence of the soaking time and annealing temperature on these properties could be optimized to avoid full recrystallization of all the sample grains beyond the temperature range of 600^{o}C. The criteria for optimization of the annealing process parameters were selected to maximize the yield strength, tensile strength and impact toughness for improved ductility, strength and material toughness for impact loading as is required of the steel wire. The combined influence of the annealing parameters on the simultaneous responses of the yield strength, tensile strength and impact toughness of the steel wire are presented in Table 9.By analyzing the response surfaces and contour plots in Fig.10,11,12, the achievable optimal yield strength, tensile strength and impact toughness values were found to be 678.896 MPa, 779.154 MPa and 42.6474 J with 95% confidence interval which ensures that the probability of the effectiveness of the optimization procedure is greater than 0.05. The corresponding parameters that yielded these optimal valueswere temperature of 500oC and soaking time of 22.32 minutes.

TABLE 9
Optimal values for the tensile properties and annealing parameters of 20% cold drawn steel.

Factor	Name	Level	Low Level	High Level	Std. Dev.	Coding
x1	Temp	500	500	650	0	Actual
x2	Time	22.32	10	60	0	Actual

Response	Prediction	SE Mean	95% CI low	95% CI high	SE Pred	95% PI low	95% PI high
Yield strength	678.896	11.32	654.61	703.18	22.02	631.67	726.12
Tensile strength	779.154	13.71	749.74	808.57	26.67	721.96	836.35
Impact toughness	42.6474	0.99	40.52	44.77	1.92	38.52	46.78

The experiment conducted at the optimum condition results in values of 679.145MPa for the yield strength, 778.874 for the tensile strength and 43.395 J for the impact toughness. These could be said to be in agreement with the predicted values.This procedure is usually acceptable for the validation of the results under the specified conditions [28], [29].

4. CONCLUSION

The yield strength, tensile strength and impact toughness of cold drawn 0.12wt% C steel were evaluated when subjected to annealing process towards obtaining the annealing parameters that will be suitable for improving these properties of cold drawn steel to prevent the steel from the influence of cold drawing which results in fracture failure when such steel is subjected to impact loads. The annealing temperature and soaking time of annealing are found to influence these properties to a large extent as exposed in the Response Surface Analysis of the properties. The model developed by the RSM describing the experiment data shows that conclusion could be drawn from the model of the individual and combined interaction influence of the annealing parameters on the yield strength, tensile strength and impact toughness of the annealed cold drawn steel. The RSM was able to obtain the optimal values of the properties and the processing conditions under which such values could be obtained. The optimal yield strength, tensile strengths and impact toughness of the steel were obtained to be 678.90 MPa, 779.15 MPa and 42.65 J respectively for the annealed 20% cold drawn steel. The RSM could be useful to obtain desired properties of annealed cold drawn steel by controlling the process parameters during annealing.

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