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STATISTICAL OPTIMIZATION OF THE MECHANICAL PROPERTIES OF HEAT TREATED ALUMINUM BRONZE (CU-10%AL) USING RESPONSE SURFACE METHODOLOGY.

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Abstract

Mathematical models have been derived for the prediction of the mechanical properties (Ultimate tensile strength (UTS), Yield Strength and %Elongation) of heat treated Aluminum bronze alloy. The aim of the research is to improve on the mechanical properties of the alloy using ageing heat treatment. The selected heat treatments were Solutionizing, Quenching and Ageing. Response Surface Methodology (RSM) was employed to investigate the influence of the process variables (ageing temperature and soaking time) on the mechanical properties. The two level-2 factor Central Composite Design (CCD) used in this study required 13 experiments. The cast specimens were solutionized at 900℃ for 1hr, quenched in water and then aged at temperatures of 109℃, 150℃, 250℃, 350℃ and 391℃, soaked for 5min, 25min, 73min, 120min and 140min respectively, according to the experimental design. The best combination of mechanical properties was achieved at ageing temperature of 350℃ and soaking time of 120mins which gave 565MPa for UTS, 480MPa for Yield Strength and 17.8%E. A model following a second order Polynomial which includes interaction terms was used to calculate the predicted responses. The models include:

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$$UTS = 271.61 + 1.561X_1 + 0.776X_2 + \{1.737X_1X_2 - 3.058X_1^2 - 3.247X_2^2\} \times 10^{-3}$$

$$YS = 235.7 + 0.726X_1 + 0.8809X_2 - 8.113 \times 10^{-4}X_1^2 - 3.0416 \times 10^{-3}X_2^2$$

$$\%E = -0.3548 + 0.0709X_1 + 0.1295X_2 - 2.3158 \times 10^{-4}X_1X_2 - 5.8175 \times 10^{-5}X_1^2 - 3.0416 \times 10^{-3}X_2^2$$

Keywords: Response Surface Methodology, Optimization, Solutionizing, Quenching and Ageing.

1.1 Introduction

Aluminum bronze is a type of bronze in which aluminum is the main alloying metal added to copper. Copper excels among other non-ferrous metals because of its high electrical conductivity, high thermal conductivity, high corrosion resistance, good ductility and malleability, and reasonable tensile strength [6, 8]. Aluminum bronzes have problem of self-annealing and embrittlement when slowly cooled or at a normal cooling rate as a result of the formation of γ_2 phase. This also result in deterioration of corrosion resistance and may produce a coarse structure with greatly reduced mechanical properties. A variety of aluminum bronzes have found industrial use, with most ranging from 5% to 11%Al by weight, the remaining mass copper, other alloying elements such as iron, nickel, manganese and silicon are sometimes added to aluminum bronze [3]. The addition of aluminum increases the mechanical properties of the alloy by the establishment of a face-centered-cubic (F.C.C) phase which could improve the casting and hot working properties of the alloy [2]. Aluminum bronzes have been identified as important and useful engineering materials due to their unique properties, such as high strength, excellent corrosion resistance to wear and fatigue [4]. The self-healing surface film of aluminum oxide gives aluminum bronzes excellent corrosion resistance and the tensile strength increases with increasing β phase, hence aluminum bronze is one of the versatile wear resistant engineering materials that work under a corrosive environment with high stress [5]. Aluminum bronze is the most tarnish-resistant Copper alloy and shows no serious deterioration in appearance and no significant loss of mechanical properties on exposure to most atmospheric conditions and hence their resistance to atmospheric corrosion combined with high strength is exploited in their use for bearing bushes in aircraft frames. It also shows low rate of oxidation at high temperatures and excellent resistance to sulphuric acid and sulphuric oxides [7]. [1] studied the effect of Ageing time and temperature on the microstructure and mechanical properties of Aluminum bronze alloy (Cu-10%Al). Aluminum bronzes have attracted attention in recent years because of improved mechanical properties compared to the conventional ferrous materials, thus much work has focused on developing aluminum bronze alloys with tailored mechanical and microstructural properties.

2.0 Material and methods

2.1 Materials Subheading Sub-heading - second level heading.

Materials and equipment used for the study include cope and drag (moulding box), rammer, venting wire, patterns, locating pins, brush, sieves, spades, bailout crucible furnace, moulding sand, pair of tongs, ladles, milling sand machine, copper wire, aluminum scrap, hacksaw and steel blade, lathe machine, grinding machine, milling machine, Heat treatment furnace, vice, universal tensile testing machine, water as quenching medium.

2.2 Experimental Procedures

2.2.1 Production

Sand casting was used in the production of the aluminum bronze alloy rods. The bailout crucible furnace with refractory bricks and a crucible pot placed at the centre of the furnace was used in the melting of the Cu and Al scraps. The Cu scrap was heated to about 1083℃ which is the melting temperature of Cu and then the Al scrap was charged and stirred to promote a homogenous mixture. When the melting was completed, the crucible pot was removed with the pair of tongs and hand gloves and casting into the preheated moulds was done steadily until the cavities were completely filled. The liquid alloy was allowed to solidify and cool in the mould before removal.

2.2.2 Machining

The machining operation was done using a lathe machine. This was done by clamping the ingot firmly on the lathe machine and the cutting gradually sliding along the entire length of the specimen to give the final desired shape. The specimens were machined to the required dimension of 250mm×30mm.

2.2.3 Heat Treatment

After machining the test specimens, they were heat treated in a heat treatment furnace as follows: two test specimens were kept as control and the remaining specimens solutionized at 900℃ for 1hr and then quenched in water. The quenched specimens were then aged at temperatures of 109℃, 150℃, 250℃, 350℃ and 391℃ and soaked for 5min, 25min, 73min, 120min and 140min respectively in the furnace (Table 1.2). After each ageing temperature and holding time, the specimens were removed from the furnace and allowed to cool in air.

Table 1.1, Independent variables and levels used for response surface design

Independent variables	Symbols	Ranges and levels				
		-2	-1	0	+1	+2
Ageing Temp (^oC)	X_1	109	150	250	350	391
Soaking Time(Min)	X_2	5	25	73	120	140

Table 1,1, shows the Independent variables (Ageing Temperature and Soaking Time) and the levels used for Response Surface Design Analysis.

Table 1.2 Experimental Design Matrix for Aluminum Bronze Alloy

Std order	Run order	Ageing Temp. (^oC) X_1		Soaking Time (min) X_2		UTS (MPa)	Yield Strength (MPa)	Elongation (%)
		Coded	Actual	Coded	Actual			
1	5	-1	150	-1	25			
2	1	+1	350	-1	25			
3	7	-1	150	+1	120			
4	13	+1	350	+1	120			
5	8	-2	109	0	73			
6	3	+2	391	0	73			
7	10	0	250	-2	5			
8	2	0	250	+2	140			
9	11	0	250	0	73			
10	6	0	250	0	73			
11	12	0	250	0	73			
12	4	0	250	0	73			
13	9	0	250	0	73			

2.2.4 Mechanical Tests

The Ultimate tensile, Yield strength and %Elongation tests were carried out using digital hydraulic universal tensile testing machine, Satec series, instron 600DX. When the load was applied on the specimen, the pressure transducer in the hydraulic system transfers the signal of reflecting voltage change into the computer system. The deformation signal is transferred to the computer through photoelectric encoder. Thus, the computer system acquires the signal of load deformation and displays test data and curves in real time.

3.0 Results and Discussions

Table 1.3: Result of Ultimate Tensile Strength (UTS), %Elongation (%E) and Yield Strength Test

Specimen Type	UTS(MPa)	%E	Yield Strength (MPa)
As Cast	455	40	310
Solutionized	573	23	405
Quenched	650	5	516

Table 1.4, Heat Treatment Result

		Factor 1	Factor 2	Response 1	Response 2	Response 3
Std	Run	A:AGEING TEMP.	B:SOAKING TIME	UTS	YEILD STRENGHT	% E
		0C	MIN	MPa	MPa	%
1	5	150	25	461	350	11.15
2	1	350	25	478	411	18.25
3	7	150	120	515	405	15.1
4	13	350	120	565	480	17.8
5	8	109	73	458	355	12.2
6	3	391	73	500	470	19.4
7	10	250	5	476	375	14.1
8	2	250	140	575	455	16.5
9	11	250	73	540	425	16.9

10	6	250	73	543	429	17.02
11	12	250	73	541	431	17
12	4	250	73	543	426	16.95
13	9	250	73	540	427	17.01

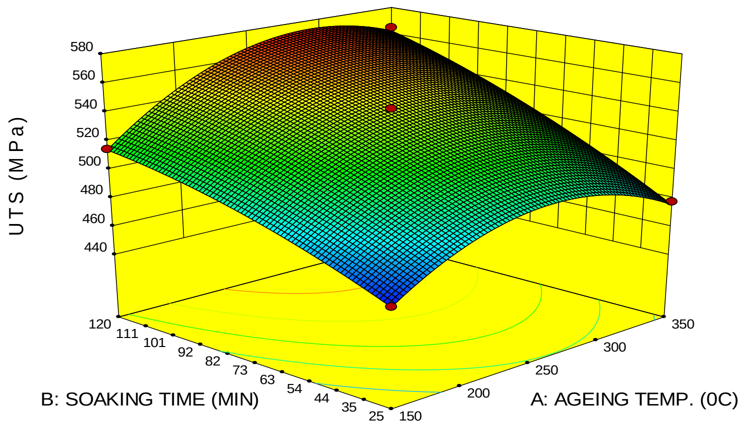

Figure 1.1: 3D Plot of UTS

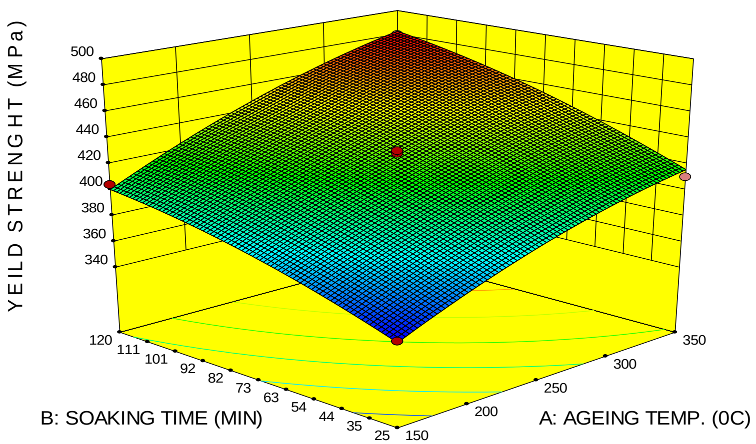

Figure 1.2: 3D Plot of Yield Strength

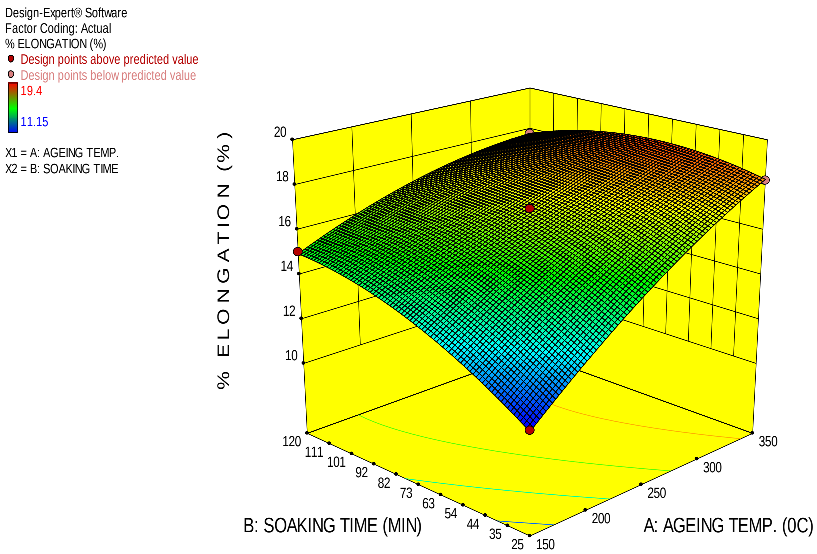

Figure 1.3: 3D Plot of % Elongation

Table 1.3, showed the ultimate tensile strength values for the solutionized and water quenched specimens as 573MPa and 650MPa respectively. The solutionized specimen has a low tensile strength value than the quenched specimen because at the solutionizing temperature of 900^{o}C, the alloy consists entirely of the solid solution β phase which is soft and ductile and had a higher tensile strength than the as cast specimen, while water quenching from 900^{o}C, produced a structure consisting of the martensitic phase β' which is a supersaturated solid solution that is very hard and brittle. In order to have a better combination of mechanical properties in terms of strength and ductility, the quenched specimens were aged at different temperatures and soaking times. From Table 1.4 and Fig 1.1, it was observed that the ultimate tensile strength values increased with increase in ageing temperature and soaking time. The highest ultimate tensile strength values were obtained in specimens aged at 250°C and 350°C and soaked for 140min and 120min respectively, while the least ultimate tensile strength value was obtained at ageing temperature of 109°C soaked for 73min. The corresponding UTS values are 575MPa, 565MPa and 458MPa respectively. These values were obviously higher than the value of the as cast specimen which was 455MPa indicating that the finely dispersed precipitates of α and γ_2 phases formed during the ageing heat treatment impeded dislocation movement during deformation and thereby strengthened the alloy.

Table 1.4 and Fig 1.2, also showed that the yield strength values increased with increase in ageing temperatures and soaking time. As cast specimen has yield strength of 310MPa which was far less than the yield strengths of all the heat-treated specimens. The quenched specimen has the highest yield strength of 516MPa compared to the solutionized and aged specimens which was as a result of its martensitic structure that is very hard. The highest yield strength of 480MPa was obtained at ageing temperature of 350°C for 120min.

Also from Table 1.4 and Fig 1.3, it was observed that the percentage elongation of the aged specimens increased with increase in ageing temperature and soaking time when compared with the value of the quenched specimen which was 5%. The as cast specimen has the highest percentage elongation of 40% which indicates it is more ductile than the heat-treated specimens. The maximum %Elongation values were obtained at ageing temperatures of 391°C and 350°C soaked for 73min and 25min with values of 19.4 and 18.25 respectively.

Table 1.5A, Sequential Model Sum of Squares for UTS

Source	**Sum of Squares**	**Df**	**Mean Square**	**F Value**	**p-value Prob > F**	**Remarks**
Mean vs Total	3.489E+006	1	3.489E+006			
Linear vs Mean	11867.65	2	5933.83	8.62	0.0067	
2FI vs Linear	272.25	1	272.25	0.37	0.5577	
Quadratic vs 2FI	6581.97	2	3290.99	793.04	< 0.0001	Suggested
Cubic vs Quadratic	7.35	2	3.67	0.85	0.4823	Aliased
Residual	21.70	5	4.34			
Total	3.508E+006	13	2.698E+005			

Table 1.5B, Sequential Model Sum of Squares for UTS

Source	Sequential p-value	Lack of Fit p-value	Adjust R-Squared	Predicted R Squared	**Remarks**
Linear	0.0067	< 0.0001	0.5595	0.3402	
2FI	0.5577	< 0.0001	0.5299	0.2435	
Quadratic	< 0.0001	0.1669	0.9973	0.9917	Suggested
Cubic	0.4823	0.0801	0.9972	0.9566	Aliased

From tables 1.5A&B, the sequential model sum of squares (linear, two factor interactions 2FI, Quadratic and cubic polynomial) the quadratic model was selected by design expert 9.0.2 version due to its highest order polynomial.

Table 1.6, Analysis of Variance (ANOVA) for the fitted Quadratic Model for UTS

Source	**Sum of Squares**	**Df**	**Mean Square**	**F Value**	**p-value Prob > F**	
Model	18721.87	5	3744.37	902.29	< 0.0001	Significant
A-AGEING TEMP.	*1997.02*	*1*	*1997.02*	*481.23*	*< 0.0001*	
B-SOAKING TIME	*9870.63*	*1*	*9870.63*	*2378.55*	*< 0.0001*	
AB	*272.25*	*1*	*272.25*	*65.60*	*< 0.0001*	
A^2	*6503.17*	*1*	*6503.17*	*1567.08*	*< 0.0001*	

B^2	*373.26*	*1*	*373.26*	*89.94*	*< 0.0001*	
Residual	29.05	7	4.15			
Lack of Fit	*19.85*	*3*	*6.62*	*2.88*	*0.1669*	*not significant*
Pure Error	*9.20*	*4*	*2.30*			
Cor Total	18750.92	12				

Std. Dev.	2.04	R-Squared	0.9985
Mean	518.08	Adj R-Squared	0.9973
C.V. %	0.39	Pred R-Squared	0.9917
PRESS	155.52	Adeq Precision	85.639

Table 1.6, shows the result of statistical analysis of variance (ANOVA) for UTS carried out to determine the significance of the fitness of the selected quadratic model as well as the significance of individual terms and their interaction on the chosen response. From the regressors incorporated in the model, F-value of 902.29 with P-value of <0.0001 implies that the model is significant at 95% confidence level. The P-value (probability of error value) is used to check the significance of each regression coefficient and the interaction effect of each cross product. In the case of the model terms, the P-value < 0.05 shows that the model terms are significant, in this case A, B, AB, A^2, B^2 are significant model terms. Values >0.1indicate the model terms are not significant.

The as fitted presents an R-Squared value of 0.9985 and standard deviation of 2.04. Only two factors (ageing temperature and soaking time) were found to be statistically important (significant) for increase in the ultimate tensile strength of Aluminum bronze at confidence level of 95%. A low value of coefficient of variation (0.39%), showed a high degree of precision and reliability of the values. The lack of fit test with P-value of 2.88, which is not significant, indicates that the model fitted to the experimental data. The predicted R-Squared value of 0.9917 is in reasonable agreement with the Adjusted R-Squared value of 0.9973, i.e. the difference is less than 0.2 and their R^2 values close to unity. This indicates that the data fits with the model. Adeq precision measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 85.639 indicates an adequate signal.

The Equation of UTS in actual factors, where: X_1 =Ageing temperature, and X_2 =Soaking time.

$$\mathbf{UTS = 271.61 + 1.561X_1 + 0.776X_2 + 1.737 \times 10^{-3}X_1X_2 - 3.058 \times 10^{-3}X_1^2 - 3.247 \times 10^{-3}X_2^2} \quad \textbf{(1)}$$

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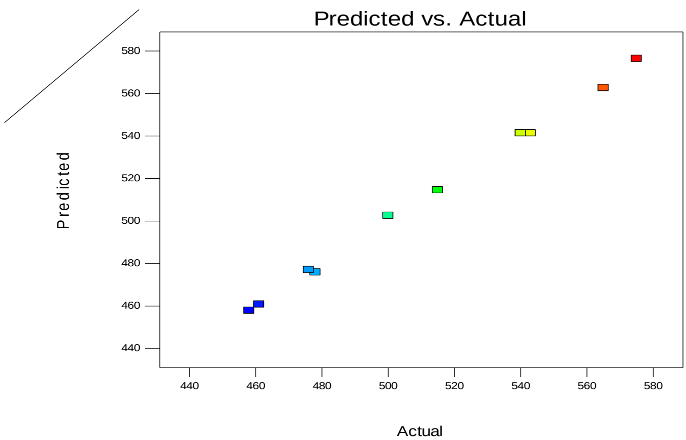

Fig 1.4: Graph of Predicted vs Actual Values (UTS).

Fig 1.4, The graph shows that there is a very good correlation between the actual values and the values predicted by the model for UTS.

Table 1.7A: Sequential Model Sum of Squares for Yield Strength

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob > F	
Mean vs Total	2.276E+006	1	2.276E+006			
Linear vs Mean	18177.07	2	9088.54	103.04	< 0.0001	
2FI vs Linear	49.00	1	49.00	0.53	0.4854	
Quadratic vs 2FI	696.25	2	348.13	17.82	0.0018	Suggested
Cubic vs Quadratic	103.43	2	51.71	7.76	0.0293	Aliased
Residual	33.33	5	6.67			
Total	2.295E+006	13	1.765E+005			

Table 1.7B: Suggested Model for Yield Strength

Summary (detailed tables shown below)

Source	Sequential p-value	Lack of Fit p-value	Adjusted R-Squared	Predicted R-Squared	
Linear	< 0.0001	0.0040	0.9445	0.9221	
2FI	0.4854	0.0033	0.9417	0.8850	
Quadratic	0.0018	0.0508	0.9877	0.9557	Suggested
Cubic	0.0293	0.2569	0.9958	0.9641	Aliased

From tables 1.7A&B, the sequential model sum of squares (linear, two factor interactions 2FI, Quadratic and cubic polynomial) the quadratic model was selected by design expert 9.0.2 version due to its highest order polynomial.

Table 1.8: Model Summary Statistics for Yield Strength

Model Summary Statistics

Source	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS
Linear	9.39	0.9537	0.9445	0.9221	1483.96
2FI	9.62	0.9563	0.9417	0.8850	2191.27

Quadratic	4.42	0.9928	0.9877	0.9557	843.72	Suggested
Cubic	2.58	0.9983	0.9958	0.9641	684.25	Aliased

Table 1.8, Model Summary Statistics, Focuses on the model maximizing the "Adjusted R-Squared" and the "Predicted R-Squared" values.

Table 1.9: ANOVA Table for Yield Strength

ANOVA for Response Surface Quadratic 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	18922.33	5	3784.47	193.72	< 0.0001	Significant
A-AGEING TEMP.	*11147.83*	*1*	*11147.83*	*570.64*	*< 0.0001*	
B-SOAKING TIME	*7029.25*	*1*	*7029.25*	*359.81*	*< 0.0001*	
AB	*49.00*	*1*	*49.00*	*2.51*	*0.1573*	
A^2	*457.83*	*1*	*457.83*	*23.44*	*0.0019*	
B^2	*327.61*	*1*	*327.61*	*16.77*	*0.0046*	
Residual	136.75	7	19.54			
Lack of Fit	*113.55*	*3*	*37.85*	*6.53*	*0.0508*	*not significant*
Pure Error	*23.20*	*4*	*5.80*			
Cor Total	19059.08	12				

Std. Dev.	0.067	R-Squared	0.9995
Mean	16.11	Adj R-Squared	0.9992
C.V. %	0.41	Pred R-Squared	0.9975
PRESS	0.16	Adeq Precision	182.173

Table 1.10: significant model terms for Yield Strength

Factor	Coefficient Estimate	Df	Standard Error	95% CI Low	95% CI High	VIF
Intercept	16.98	1	0.030	16.91	17.05	
A-AGEING TEMP.	2.50	1	0.024	2.44	2.55	1.00
B-SOAKING TIME	0.86	1	0.024	0.81	0.92	1.00
AB	-1.10	1	0.033	-1.18	-1.02	1.00
A^2	-0.58	1	0.025	-0.64	-0.52	1.02
B^2	-0.83	1	0.025	-0.89	-0.77	1.02

From table 1.9, The ANOVA table for the Yield Strength shows that Model F-value of 193.72 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. Values of "Prob > F" less than 0.05 indicate model terms are significant. In this case A, B, AB, A^2, B^2 are significant model terms (Table 1.10). Values greater than 0.1indicate the model terms are not significant. The "Pred R-Squared" of 0.9975 is in reasonable agreement with the "Adj R-Squared" of 0.9992; i.e. the difference is less than 0.2. "Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 182.173 indicates an adequate signal.

Equation of Yield Strength in Terms of Coded Factors

$$\boldsymbol{YS = 427.6 + 37.33 * A + 29.64 * B + 3.5 * AB - 8.11 * A^2 - 6.86 * B^2} \quad \textbf{(2)}$$

The equation in terms of coded factors can be used to make predictions about the Yield Strength for given levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels of the factors are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients.

The Equation of Yield Strength in terms of Actual factors, where: X_1=Ageing temperature and X_2=Soaking time

$$\boldsymbol{YS = 235.7 + 0.726X_1 + 0.8809X_2 + 7.368 \times 10^{-4}X_1X_2 - 8.113 \times 10^{-4}X_1^2 - 3.0416 \times 10^{-3}X_2^2} \quad \textbf{(3)}$$

Eliminating the non-significant terms with values of “Prob>F” greater than 0.100. Equation (2) reduces to:

$$\boldsymbol{YS = 235.7 + 0.726X_1 + 0.8809X_2 - 8.113 \times 10^{-4}X_1^2 - 3.0416 \times 10^{-3}X_2^2} \quad \textbf{(4)}$$

The equation in terms of actual factors can be used to make predictions about the Yield Strength for given levels of each factor. Here, the levels should be specified in the original units for each factor.

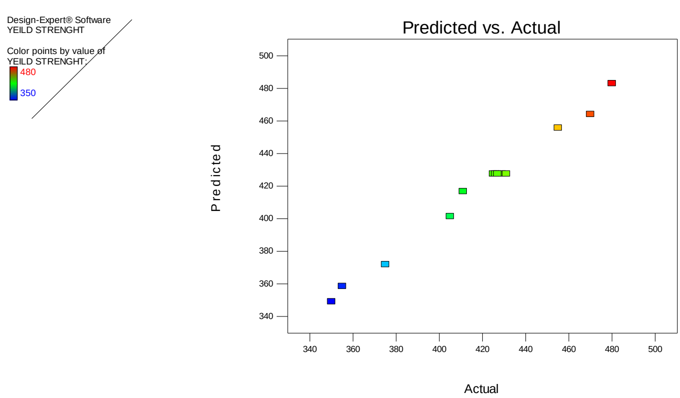

Fig 1.5: Predicted vs Actual values for Yield Strength

Fig 1.5, The graph shows that there is a very good correlation between the actual values and the values predicted by the model for Yield Strength.

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Table 1.11: Sequential Model Sum of Squares for %E

Sequential Model Sum of Squares [Type I]						
Source	**Sum of Squares**	**Df**	**Mean Square**	**F Value**	**p-value Prob > F**	
Mean vs Total	3372.31	1	3372.31			
Linear vs Mean	55.85	2	27.93	24.78	0.0001	
2FI vs Linear	4.84	1	4.84	6.78	0.0286	
Quadratic vs 2FI	6.40	2	3.20	721.28	< 0.0001	Suggested
Cubic vs Quadratic	0.020	2	9.837E-003	4.33	0.0812	Aliased
Residual	0.011	5	2.274E-003			
Total	3439.43	13	264.57			

Table 1.12: Suggested Model for %E

Source	**Sequential p-value**	**Lack of Fit p-value**	**Adjusted R-Squared**	**Predicted R-Squared**	
Linear	0.0001	< 0.0001	0.7985	0.6878	
2FI	0.0286	< 0.0001	0.8723	0.7897	
Quadratic	< 0.0001	0.1761	0.9992	0.9975	Suggested
Cubic	0.0812	0.5209	0.9996	0.9986	Aliased

Tables 1.11 & 1.12, Sequential Model Sum of Squares, The Quadratic Model was selected which has the highest order polynomial where the additional terms are significant and the model is not aliased.

Table 1.13: Model Summary Statistics for %E

Model Summary Statistics						
Source	**Std. Dev.**	**R-Squared**	**Adjusted R-Squared**	**Predicted R-Squared**	**PRESS**	
Linear	1.06	0.8321	0.7985	0.6878	20.95	
2FI	0.85	0.9042	0.8723	0.7897	14.12	
Quadratic	0.067	0.9995	0.9992	0.9975	0.16	Suggested

Cubic 0.048	0.9998	0.9996	0.9986	0.096	Aliased

Table 1.13, Model Summary Statistics, Focuses on the model maximizing the "Adjusted R-Squared" and the "Predicted R-Squared" values.

Table 1.14: ANOVA Table for % Elongation

ANOVA for Response Surface Quadratic 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	67.09	5	13.42	3025.57	< 0.0001	Significant
A-AGEING TEMP.	*49.91*	*1*	*49.91*	*11254.31*	*< 0.0001*	
B-SOAKING TIME	*5.94*	*1*	*5.94*	*1339.62*	*< 0.0001*	
AB	*4.84*	*1*	*4.84*	*1091.34*	*< 0.0001*	
A^2	*2.35*	*1*	*2.35*	*530.86*	*< 0.0001*	
B^2	*4.81*	*1*	*4.81*	*1085.16*	*< 0.0001*	
Residual	0.031	7	4.435E-003			
Lack of Fit	*0.021*	*3*	*6.975E-003*	*2.76*	*0.1761*	*not significant*
Pure Error	*0.010*	*4*	*2.530E-003*			
Cor Total	67.12	12				

Std. Dev.	0.067	R-Squared	0.9995
Mean	16.11	Adj R-Squared	0.9992
C.V. %	0.41	Pred R-Squared	0.9975
PRESS	0.16	Adeq Precision	182.173

Table 1.15: significant model terms for %Elongation

Factor	Coefficient Estimate	df	Standard Error	95% CI Low	95% CI High	VIF
Intercept	16.98	1	0.030	16.91	17.05	
A-AGEING TEMP.	2.50	1	0.024	2.44	2.55	1.00

B-SOAKING TIME	0.86	1	0.024	0.81	0.92	1.00
AB	-1.10	1	0.033	-1.18	-1.02	1.00
A^2	-0.58	1	0.025	-0.64	-0.52	1.02
B^2	-0.83	1	0.025	-0.89	-0.77	1.02

From table 1.14, The ANOVA table for %Elongation shows that the Model F-value of 3025.57 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. Values of "Prob > F" less than 0.05 indicate model terms are significant. In this case A, B, AB, A^2, B^2 are significant model terms (Table 1.15). Values greater than 0.1 indicate the model terms are not significant. The "Lack of Fit F-value" of 2.76 implies the Lack of Fit is not significant relative to the pure error. There is a 17.61% chance that a "Lack of Fit F-value" this large could occur due to noise. Non-significant lack of fit is good. The "Pred R-Squared" of 0.9975 is in reasonable agreement with the "Adj R-Squared" of 0.9992; i.e. the difference is less than 0.2. "Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 182.173 indicates an adequate signal.

Equation of %E in Terms of Coded Factors

$$\%\boldsymbol{E} = \mathbf{16.98} + \mathbf{2.5} * \boldsymbol{A} + \mathbf{0.86} * \boldsymbol{B} - \mathbf{1.1} * \boldsymbol{AB} - \mathbf{0.58} * \boldsymbol{A}^{\mathbf{2}} - \mathbf{0.83} * \boldsymbol{B}^{\mathbf{2}} \quad \textbf{(5)}$$

The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels of the factors are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients.

The Equation of %Elongation in Actual Factors; where: X_1=Ageing temperature and X_2=Soaking time.

$$\%E = 0.3548 + 0.0709X_1 + 0.1295X_2 - 2.3158 \times 10^{-4}X_1X_2 - 5.8175 \times 10^{-5}X_1^2 - 3.6864 \times 10^{-4}X_2^2 \quad \textbf{(6)}$$

The equation in terms of actual factors can be used to make predictions about the response for given levels of each factor. Here, the levels should be specified in the original units for each factor. This equation should not be used to determine the relative impact of each factor because the coefficients are scaled to accommodate the units of each factor and the intercept is not at the center of the design space.

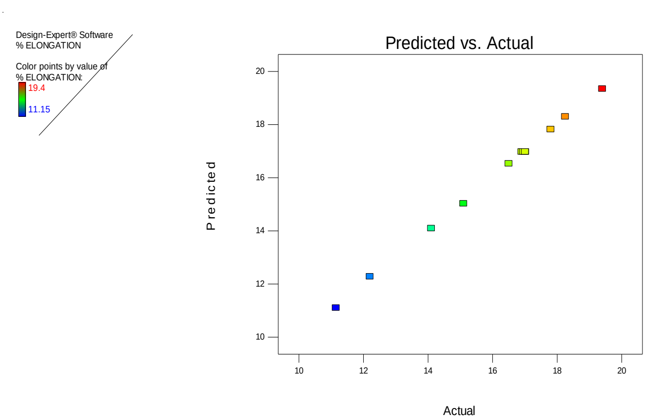

Fig 1.6: Predicted vs. Actual values (%E)

Fig 1.6, The graph shows that there is a very good correlation between the actual values and the values predicted by the model for % Elongation.

Table 1.16: Design Summary of the experimental analysis

Factor	Name	Units	Type	Subtype	Minimum	Maximum	Coded	Values	Mean	Std. Dev.
A	AGEING TEMP.	0C	Numeric	Continuous	108.57	391.42	-1=150	1=350	250	81.65
B	SOAKING TIME	MIN	Numeric	Continuous	5.32	139.67	-1=25	1=120	72.5	38.78

Response	Name	Units	Analysis	Minimum	Maximum	Mean	Std. Dev.	Ratio	Trans	Model
R1	UTS	MPa	Polynomial	458	575	518.07	39.53	1.26	None	Quadratic
R2	YS	MPa	Polynomial	350	480	418.38	39.85	1.37	None	Quadratic
R3	% E	%	Polynomial	11.15	19.4	16.11	2.37	1.74	None	Quadratic

4.0. Conclusion

From the research, the following conclusions were drawn based on the experimental results and statistical analysis:

1. Solutionizing the as cast alloy at 900°C for 1hr produced a homogeneous solid solution β phase which impacted better mechanical properties than the Cu_9Al_4 intermetallic compound of the as cast alloy.
2. Water quenching the alloys from the solutionization temperature of 900°C transformed all the β phase into β' phase structure which is a supersaturated solid solution that is harder and more brittle than the as cast alloy.
3. Ageing heat treatment transformed the martensitic β' phase into finely dispersed precipitates of α and γ_2 phases which have better combination of mechanical properties in terms of tensile strength and hardness than the as cast alloy, quenched, and solutionized specimens.
4. The results of the statistical analysis of variance (ANOVA) determined the significance of the fitness of the selected models as well as the significance of the individual terms and their interactions on the chosen responses.
5. The models obtained can be used to make predictions about the responses (UTS, Yield strength and %E) for given levels of each factor (Ageing temperature and soaking time).

5.0 Recommendation

The following recommendations are hereby made:

1. Further studies should be carried out to examine the effect of heat treatment on aluminum bronze alloy with other alloying elements like Fe, Ni, Mn, Mg and at different percentages of Cu and Al.
2. Studies should be carried out on the effect of these alloying elements on the corrosion resistance of this alloy.
3. Mechanical tests should be conducted on this alloy at sub-zero and elevated temperatures to determine their reliability.
4. Also natural oil, kerosene and brine should be examined as quenchants, to establish the one that will give optimum mechanical properties.

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