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MODELLING AND EXPERIMENTAL INVESTIGATION OF COPPER-ZINC ALLOY USING SPLIT-SPLIT PLOT DESIGN

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ABSTRACT: This study focused on the modelling and experimental investigation of Copper-Zinc alloy using Split-split plot design. The effects of process parameters such as percentage by volume of material, material type (copper and zinc), pressure and their interactions on the mechanical properties of the produced copper-zinc alloy using split-split plot design was investigated. The mechanical properties examined in this study include; tensile strength, modulus of elasticity, shear modulus and hardness. The values obtained from the evaluation of these mechanical properties were imputed into the analytical design of the split-split plot to obtain its numerical designs. Interactive model for the process parameters were also developed for this study. The sum of squares (SS) and the mean of squares (MS) were calculated from the numerical designs of split-split plot to obtain the Fisher's ratio (F_{cal}) values. The results of the calculated Fisher's ratio at significant value of 0.05 for the process parameters and their interactions ranges from -57.70 to 8.50, and were presented on analysis of variance (ANOVA) table. The results obtained shows that there is strong interaction between pressure, percentage by volume of zinc and copper in the production zinc-copper alloy in alloy manufacturing industries.

Keywords: Copper-Zinc Alloy, Mechanical Properties, Modelling, Process Parameters, Split-Split Plot Design.

1. INTRODUCTION

Brass is an alloy of copper and zinc in proportions which can be varied to achieve varying mechanical and electrical properties. Brass is an alloy of 70% copper and 30% zinc [1]. However, 'the proportions of copper and zinc can be varied to obtain a range of brasses with varying mechanical properties. Brass has higher malleability and low melting point (900°C to 940°C) depending on its composition. By varying the proportions of copper and zinc, the properties of the brass can be changed, allowing hard and soft brasses to be produced. Brass has the desirable properties that make it ideal for use as a rolling element material, such as good frictional properties against hardened steel components, copper-zinc alloy also have reasonable strength, high toughness and excellent thermal conductivity'. In addition, brass has good machining and joining characteristics that make it cost-effective [2]. The malleability of copper-zinc alloy has made it the metal of choice [3]. This alloy had applications where low friction are required such as locks, gears, bearings, doorknobs, ammunition, and valves. Improper analysis of process parameters such as percentage by volume of copper and zinc, pressure and their interaction in the manufacture of copper-zinc alloy had poses great challenges in alloy manufacturing. Moreover, the split-plot design which is an experiment design includes at least one hard-to-change factor that is difficult to completely randomize because of time or cost constraints [4]. According to Olodu and Osarenmwinda [4], stated that in a split-plot experiment, levels of the hard-to-change factor were held constant for several experimental runs, which were collectively treated as a whole plot. 'The easy-to-change factors were varied during these runs, each combination of which is considered a sub-plot within the whole plot. In addition, they randomize the order in which they run both the whole plots and the sub-plots within whole plots. In simple terms, a split-plot experiment is a blocked experiment, where the blocks themselves serve as experimental units for a subset of the factors. Thus, there were two levels of experimental units, the blocks are referred to as whole plots; while the experimental units within blocks are called split plots, split units, or subplots. According to them [4], one randomization was conducted to determine the assignment of block-level treatments to whole plots. Then, as always in a blocked experiment, a randomization of treatments to split-plot experimental units occurred within each block or whole plot.' Olodu and Osarenmwinda [4] examined the effect of process parameters such as temperature in the production of polypropylene-grass composite using split-split plot experimental design, their results show that temperature contributes significantly to the production of composites in polymeric industries. Aviles and Pinheiro [5] examined the experiments that have complete randomization order of runs which was not feasible or might be too expensive to use when performed. They concluded from their study that the use of split-plot designs and models are feasible, efficient and cheap. Goldsmith and Gaylor [6]' carried out extensive investigation on optimal designs for estimating variance components in a completely random nested classification. Loeza-Serrano and Donev [7] 'constructed D-Optimal design for variance components estimation in a three-stage crossed and nested classification. For experiments that include both crossed and nested factor in the same model, no assumption of a complete random model has been made. Ankenman et al; Aviles and Pinheiro [8,5] investigations indicate that experiments involving complete randomization of order of runs which is not feasible or too expensive to use is performed using split plot models. Chunping *et al* [9] carried out a study aimed to model fundamental bonding characteristics and performance of composite materials. In their work, mathematical model and a computer simulation model were developed to predict the variation of inter-element (strand) contact during mat consolidation. The mathematical predictions and the computer simulations agree well with each other'. Their results showed that the relationship between the inter-element contact and the mat density was highly nonlinear and was significantly affected by the wood density and the element thickness.

This study therefore focused on the modelling and experimental investigation of Copper-zinc alloy using Split-split plot design.

2. MATERIALS AND METHODS

2.1 Materials

The materials used in this study were zinc and copper. These materials were subjected to various production pressures (hot pressures) ranging from 20GPa to 78 GPa respectively. These materials produced at various pressures were evaluated for mechanical properties after cooling.

2.2 Method of Data Collection

The various samples of the developed copper-zinc alloy that were produced at various pressure were tested according to American Standard of Testing Machine (ASTM) using the tensometer and Charpy Impact Test machines respectively. The data obtained were further evaluated for mechanical properties for the developed copper-zinc alloy. Furthermore, Samples were tested on a 10-ton DAK tensile testing machine at a constant cross head speed of 1 mm/min. Standard samples of tensile specimens ASTM-E8M are prepared for testing. A total of 6 samples were tested in each case and average values were obtained.

2.3 Evaluation of Developed Copper-Zinc Alloy for Mechanical Properties at Various Pressures

The developed copper-zinc alloy samples were evaluated for mechanical strength (tensile strength, modulus of elasticity, Brinell hardness and shear modulus) using Equation 1 to 4 respectively [10].

$$\text{Tensile strength} = \frac{\text{Maximum Load}}{\text{Original Cross – Sectional Area}} \quad (1)$$

$$\text{modulus of Elasticity, E} = \frac{Stress}{Strain} = \frac{FL_o}{L_m - L_o} \quad (2)$$

Where F= applied force, l_o=original length; l_m=Final length

$$\text{shear modulus} = \frac{\text{shear stress}}{\text{shear strain}} = \frac{\frac{F}{A}}{\frac{x}{y}}. \quad (3)$$

Where F= applied force: A=Cross-sectional Area; x=extension; y-original length

$$\text{Brinell Hardness Number (BHN)} = \frac{2P}{\pi D[D - \sqrt{D^2 - d^2}} \quad (4)$$

Where P is the load in kilogram, D is the steel ball diameter in millimeter, and d is the depression diameter or indentation diameter.

2.4 The Split-Split Plot Design

The split-split plot design which is an experimental design was used to investigate the interaction between material type, percentage by volume of material and pressure on the mechanical properties of the produced copper-zinc alloy. In simple terms, a split-split plot experiment is a blocked experiment, where the blocks themselves serve as experimental units for a subset of the factors [11]. Analytical and numerical designs using split-split plot design was carried out to investigate the effects of process parameters in the developed copper-zinc alloy.

2.4.1 The F-Test

The F-test is used for comparing the factors of the total deviation. Statistical significance is tested for by comparing the F test statistic.

$$F = \frac{Variance\ between\ treatments}{Variance\ within\ treatments} \quad (5)$$

$$F = \frac{MS_{Treatments}}{MS_{Error}} = \frac{SS_{Treatments/(I-1)}}{SS_{Error}/(\ nT-1)} \quad (6)$$

2.5 Hypothesis Statements for Copper-Zinc Alloy

The null hypothesis with its alternative was formulated for copper-zinc alloy as follows:
Null Hypothesis (H_o)***:*** The percentage by volume of material, material type, pressure and their interactions contribute significantly to the mechanical properties of the developed copper-zinc alloy at a significant value (α-value) of 0.05.
Alternate Hypothesis (H_1)***:*** The percentage by volume of material, material type, pressure and their interactions does not contribute significantly to the mechanical properties of copper-zinc alloy produced at α-value of 0.05.

3. RESULTS AND DISCUSSION

3.1 The Interactive Model Developed for Copper-Zinc Alloy

The split-split plot design which is an experimental design was used to investigate the interaction between mechanical strength of copper-zinc alloy, material type, percentage by volume of material and pressure. The results obtained from the evaluation of mechanical properties are shown appendix A1, A2, A3 and A4 respectively. These results were imputed into the analytical design of the split-split plot design to obtain its numerical design, this was furtherly presented on ANOVA Table 1.

The Interactive model developed is depicted as:

$$X_{ijkl} = \mu + \gamma_i + \beta_j + \delta_l + y_k + \gamma\beta_{ij} + \gamma y_{ik} + \beta y_{jk} + \gamma\delta_{il} + \beta\delta_{jl} + y\delta_{lk} + \gamma\beta y_{ijk} + \gamma\beta\delta_{ijl} + \gamma y\delta_{ikl} + \beta y\delta_{jkl} + \gamma\beta\delta y_{ijkl} + \varepsilon_{ijkl} \tag{7}$$

Where:
μ = Mean response; γ_I= Block variable (mechanical properties); β_j = Block variable (pressure); δ_l = Treatment Variable (percentage by volume of material); y_k= Treatment Variable (type of material); $\gamma\beta_{ij}$= Block interaction (mechanical properties and pressure interaction); γy_{ik}= Block and Treatment interaction (mechanical properties and type of material interaction); βy_{jk}=Treatment Interaction (pressure and type of material interaction); $\gamma\delta_{il}$= Block and Treatment interaction (mechanical properties and percentage by volume of material interaction); $\beta\delta_{jl}$= Block and Treatment interaction (pressure and percentage by volume of material interaction); $y\delta_{lk}$= Treatment Interaction (percentage by volume of material and type of material interaction); $\gamma\beta y_{ijk}$= Block and Treatment interaction (mechanical properties, pressure and type of material interaction); $\gamma\beta\delta_{ijl}$= Block and Treatment interaction (mechanical properties, pressure and Percentage by volume of material interaction); $y\gamma\delta_{ikl}$= Block and Treatment interaction (mechanical properties, type of material and Percentage by volume of material interaction); $\beta y\delta_{jkl}$ = Block and Treatment interaction (pressure, type of material and Percentage by volume of material interaction); $\gamma\beta\delta y_{ijkl}$= Block and Treatment interaction (mechanical properties, pressure, type of material and percentage by volume of material interaction); X_{ijkl}= Response Variable; ε_{ijkl}= Error term

3.2 Statistical Computations of Sum of Squares for Copper-Zinc Alloy

Equations 8 to 22 were used to calculate for the sum of squares for the process parameters and their interactions which were used to investigate the effects of pressure and its interactions on copper-zinc alloy using Split-Split Plot experimental design analysis, the obtained results were presented on ANOVA Table 1 shown below.

A) Total Sum of Squares (SS_T)

$$SS_T = \sum_{i=1}^{I=4}\sum_{j=1}^{J=11}\sum_{k=1}^{K=2}\sum_{l=1}^{L=7} X_{ijkl}^2 - \frac{X_{....}^2}{IJLK} \tag{8}$$

Where I=4, J=11, K=2, L=7

B) Sum of Squares for Materials (SS_A)

$$SS_A = \sum_{k=1}^{K=2} \frac{X^2_{..K.}}{IJL} - \frac{X^2_{....}}{IJLK} \qquad (9)$$

C) Sum of Squares for the Percentage by Volume of Materials (SS_B)

$$SS_B = \sum_{l=1}^{L=7} \frac{X^2_{...l}}{IJK} - \frac{X^2_{....}}{IJLK} \qquad (10)$$

D) Sum of Squares for Mechanical Strength (SS_C)

$$SS_C = \sum_{i=1}^{I=4} \frac{X^2_{i...}}{JKL} - \frac{X^2_{....}}{IJLK} \qquad (10)$$

E) Sum of Squares for Pressure (SS_D)

$$SS_D = \sum_{j=1}^{J=11} \frac{X^2_{.j..}}{IKL} - \frac{X^2_{....}}{IJLK} \qquad (11)$$

F) (Material Type) X (Percentage by Volume of Material) Interaction (SS_{AB})

$$SS_{AB} = \sum_{k=1}^{K=2}\sum_{l=1}^{L=7} \frac{X^2_{..kl}}{IJ} - \sum_{k=1}^{K=2} \frac{X^2_{..k.}}{IJK} - \sum_{l=1}^{L=7} \frac{X^2_{...l}}{IJK} + \frac{X^2_{....}}{IJLK} \qquad (12)$$

G) (Material type) X (Mechanical Strength) Interaction (SS_{AC})

$$SS_{AC} = \sum_{i=1}^{I=4}\sum_{k=1}^{K=2} \frac{X^2_{i.k.}}{JL} - \sum_{i=1}^{I=4} \frac{X^2_{i...}}{JKL} - \sum_{k=1}^{K=2} \frac{X^2_{..k.}}{IJL} + \frac{X^2_{....}}{IJLK} \qquad (13)$$

H) (Material type) X (Pressure) Interaction (SS_{AD})

$$SS_{AD} = \sum_{k=1}^{K=2}\sum_{j=1}^{J=11} \frac{X^2_{.jk.}}{IL} - \sum_{k=1}^{K=2} \frac{X^2_{..k.}}{IJL} - \sum_{j=1}^{J=11} \frac{X^2_{.j..}}{IKL} + \frac{X^2_{....}}{IJLK} \qquad (14)$$

I) (Percentage by Volume of Material) X (Mechanical Strength) Interaction (SS_{BC})

$$SS_{BC} = \sum_{i=1}^{I=4}\sum_{l=1}^{L=7} \frac{X^2_{i..l}}{JK} - \sum_{i=1}^{I=4} \frac{X^2_{i...}}{JKL} - \sum_{l=1}^{L=7} \frac{X^2_{...l}}{IJK} + \frac{X^2_{....}}{IJLK} \qquad (15)$$

J) (Percentage by volume of material) X (Pressure) Interaction (SS_{BD})

$$SS_{BD} = \sum_{j=1}^{J=11}\sum_{l=1}^{L=7} \frac{X^2_{.j.l}}{IK} - \sum_{j=1}^{J=11} \frac{X^2_{.j..}}{IKL} - \sum_{l=1}^{L=7} \frac{X^2_{...l}}{IJK} + \frac{X^2_{....}}{IJLK} \qquad (16)$$

K) (Mechanical Strength) X (Pressure) Interaction (SS_{CD})

$$SS_{CD} = \sum_{i=1}^{I=4}\sum_{j=1}^{J=11} \frac{X^2_{ij..}}{KL} - \sum_{i=1}^{I=4} \frac{X^2_{i...}}{JKL} - \sum_{j=1}^{J=11} \frac{X^2_{.j..}}{IKL} + \frac{X^2_{....}}{IJLK} \qquad (17)$$

L) (Material type) X (Percentage by Volume of Material) X (Mechanical Strength) Interaction (SS_{ABC})

$$SS_{ABC} = \sum_{i=1}^{I=4}\sum_{k=1}^{K=2}\sum_{l=1}^{L=7} \frac{X^2_{i.kl}}{J} - \sum_{i=1}^{I=4}\sum_{k=1}^{K=2} \frac{X^2_{i.k.}}{JL} - \sum_{k=1}^{K=2}\sum_{l=1}^{L=7} \frac{X^2_{..kl}}{IJ} + \sum_{k=1}^{K=2} \frac{X^2_{..k.}}{IJL} \qquad (18)$$

M) (Material type) X (Percentage by Volume of Material) X (Pressure) Interaction (SS_{ABD})

$$SS_{ABD} = \sum_{j=1}^{J=11}\sum_{k=1}^{K=2}\sum_{l=1}^{L=7} \frac{X^2_{.jkl}}{I} - \sum_{j=1}^{J=11}\sum_{k=1}^{K=2} \frac{X^2_{.jk.}}{IL} - \sum_{k=1}^{K=2}\sum_{l=1}^{L=7} \frac{X^2_{..kl}}{IJ} + \sum_{k=1}^{K=2} \frac{X^2_{..k.}}{IJL}$$

(19)

N) (Material type) X (Mechanical strength) X (Pressure) Interaction (SS_{ACD})

$$SS_{ACD} = \sum_{i=1}^{I=4}\sum_{j=1}^{J=11}\sum_{k=1}^{K=4}\frac{X^2_{i\ j\ k\ .}}{L} - \sum_{i=1}^{I=4}\sum_{j=1}^{J=11}\frac{X^2_{i\ j\ .\ .}}{KL} - \sum_{j=1}^{J=11}\sum_{k=1}^{K=7}\frac{X^2_{.\ j\ k\ .}}{IL} + \sum_{j=1}^{J=11}\frac{X^2_{.\ j\ .\ .}}{IKL} \quad (20)$$

O) (Percentage by Volume of Material) X (Mechanical strength) X (Pressure) Interaction (SS_{BCD})

$$SS_{ACD} = \sum_{i=1}^{I=4}\sum_{j=1}^{J=11}\sum_{l=1}^{L=7}\frac{X^2_{i\ j\ .\ l}}{K} - \sum_{i=1}^{I=4}\sum_{j=1}^{J=11}\frac{X^2_{i\ j\ .\ .}}{KL} - \sum_{j=1}^{J=11}\sum_{l=1}^{L=7}\frac{X^2_{.\ j\ .\ l}}{IK} + \sum_{j=1}^{J=11}\frac{X^2_{.\ j\ .\ .}}{IKL} \quad (21)$$

P) Error Sums of Squares $(\mathbf{SS_E}) = SS_T - SS_A - SS_B - SS_C - SS_D - SS_{AB} - SS_{AC} - SS_{AD}$

$- SS_{BC} - SS_{CD} - SS_{ABC} - SS_{ABD} - SS_{ACD}$. (22)

3.2.1 Result for Effects of Pressure on Copper-Zinc Alloy Using Split-Split Plot Design

Table 1 shows Analysis of Variance (ANOVA) results for the effects of process parameters and their interactions on produced Copper-Zinc alloy.

Table 1. Analysis of Variance (ANOVA) Results for Effects of Pressure on Copper-Zinc Alloy

Sources of Variation	Sum of Squares (SS)	Degree of freedom	Mean of Squares (MS)	Fisher's Ratio F_{cal} α=0.05	Fisher's Ratio F_{Table}	Decision
SS_A	2.45	K-1=1	2.45	$\frac{MS_A}{MS_B} =$ 2.45	5.99	$F_{cal} < F_{Table}$, no enough evidence to reject null hypothesis.
SS_B	459.00	L-1=6	76.50	$\frac{MS_B}{MS_{AB}} =$ 3.89	4.28	$F_{cal} < F_{Table}$, no enough evidence to reject null hypothesis..
SS_C	2786.10	I-1=3	928.70	$\frac{MS_C}{MS_{AC}} =$ 7.43	9.28	$F_{cal} < F_{Table}$, no enough evidence to reject null hypothesis..
SS_D	2315.00	J-1=10	231.5	$\frac{MS_D}{MS_{AD}} =$ 2.00	2.98	$F_{cal} < F_{Table}$, no enough evidence to reject null hypothesis..
SS_{AB}	685.80	(K-1)(L-1)=6	114.3	$\frac{MS_{AB}}{MS_C} =$ 8.50	8.94	$F_{cal} < F_{Table}$, no enough evidence to reject null hypothesis..

SS_{AC}	337.50	(K-1)(I-1)=3	112.5	$\frac{MS_{AC}}{MS_{BC}} = 2.50$	3.16	$F_{cal} < F_{Table}$, no enough evidence to reject null hypothesis..
SS_{AD}	224.50	(K-1)(J-1)=10	22.45	$\frac{MS_{AD}}{MS_{BD}} = 2.50$	1.99	$F_{cal} > F_{Table}$, there was enough evidence to reject null hypothesis..
SS_{BC}	693.00	(L-1)(I-1)=18	38.50	$\frac{MS_{BC}}{MS_{ABC}} = 1.00$	2.01	$F_{cal} < F_{Table}$, no enough evidence to reject null hypothesis..
SS_{BD}	-15030.00	(L-1)(J-1)=60	-250.50	$\frac{MS_{BD}}{MS_{ABD}} = -57.70$	0.51	$F_{cal} < F_{Table}$, no enough evidence to reject null hypothesis..
SS_{CD}	3168.00	(I-1)(J-1)=30	105.60	$\frac{MS_{CD}}{MS_{ACD}} = 1.02$	1.37	$F_{cal} < F_{Table}$, no enough evidence to reject null hypothesis..
SS_{ABC}	1809	(K-1)(L-1)(I-1)=18	100.50	$\frac{MS_{ABC}}{MS_{D}} = 2.23$	2.98	$F_{cal} < F_{Table}$, no enough evidence to reject null hypothesis..
SS_{ABD}	-6.60	(K-1)(L-1)(I-1)=60	-0.11	$\frac{MS_{ABD}}{MS_{CD}} = -0.01$	0.17	$F_{cal} < F_{Table}$, no enough evidence to reject null hypothesis..
SS_{ACD}	6642	(K-1)(I-1)(J-1)=30	221.40	$\frac{MS_{ACD}}{MS_{BCD}} = 1.50$	1.93	$F_{cal} < F_{Table}$, no enough evidence to reject null hypothesis..
SS_{BCD}	7290.00	(L-1)(I-1)(J-1)=180	40.50	$\frac{MS_{BCD}}{MS_{E}}=5.65$	6.57	$F_{cal} < F_{Table}$, no enough evidence to reject null hypothesis..
SS_{E}	0.05	(I-1)(J-1)(K-1)(L-1)=180	9.00			
SS_{T}	11375.80	IJKL-1=615				

3.3 Discussion of the Results

Table 1 Shows that the fourteen null hypothesis H_o^1, H_o^2, H_o^3, H_o^4, H_o^5, H_o^6, H_o^7, H_o^8, H_o^9, H_o^{10}, H_o^{11}, H_o^{12}, H_o^{13}, H_o^{14}, are respectively not rejected at α-value of 0.05, suggesting that there appears to be no differential treatment and block effects. Also, interaction appears to exist between treatment and block effects.

(a)Examination of Treatment Effect of Materials (Copper-Zinc Alloy) (SS_A)

Since F_{cal}=2.45<F_{Table}=5.99, the F_{cal} is less than the F_{Table} in the statistical table, our experimental data do not furnish enough evidence for us to reject the null hypothesis H_o^1 treatment at α-value of 0.05. Our conclusion therefore is that the materials (copper and zinc) parameters contribute significantly to the mechanical property of the copper-zinc alloy produced in industries.

(b) Examination of Treatment Effect of Percentage by Volume of Materials (SS_B)

Since F_{cal}=3.89<F_{Table}=4.28, the F_{cal} is less than the F_{Table} in the statistical table, our experimental data do not furnish enough evidence for us to reject the null hypothesis H_o^2 treatment at α-value of 0.05. Our conclusion therefore is that the percentage by volume of materials parameter contributes significantly to the mechanical property of the copper-zinc alloy produced in industries.

(c) Examination of Block Effect of Mechanical Properties (SS_C)

Since F_{cal}=7.43<F_{Table}=9.28, the F_{cal} is less than the F_{Table} in the statistical table, our experimental data do not furnish enough evidence for us to reject the null hypothesis H_o^3 at α-value of 0.05. Our conclusion therefore is that the mechanical strength parameters contribute significantly to copper-zinc alloy produced in industries.

(d) Examination of Block Effect of Pressure (SS_D)

Since F_{cal}=2.00<F_{Table}=2.98, the F_{cal} is less than the F_{Table} in the statistical table, our experimental data do not furnish enough evidence for us to reject the null hypothesis H_o^4 of block effect at α-value of 0.05. Our conclusion therefore is that the pressure parameters contribute significantly to the mechanical property of the copper-zinc alloy produced in industries.

(e) Examination of Treatment Effect of Material Type and Percentage by Volume of Material Interaction (SS_{AB})

Since F_{cal}=8.50<F_{Table}=8.94, the F_{cal} is less than the F_{Table} in the statistical table, our experimental data do not furnish enough evidence for us to reject the null hypothesis H_o^5 of interaction effect of material type and percentage by volume of material interaction at α-value of 0.05. Our conclusion therefore is that the material type and percentage by volume of material interaction parameters contribute significantly to the mechanical property of the copper-zinc alloy produced in industries.

(f) Examination of Treatment Effect of Material Type and Block Effect Mechanical Strength Interaction (SS_{AC})

Since F_{cal}=2.50<F_{Table}=3.16, the F_{cal} is less than the F_{Table} in the statistical table, our experimental data do not furnish enough evidence for us to reject the null hypothesis H_o^6 interaction at α-value of 0.05. Our conclusion therefore is that the materials (copper-zinc alloy) and Mechanical Strength interaction parameters contribute significantly to copper-zinc alloy produced in industries.

(g) Examination of Treatment Effect of Material Type and Block Effect (Pressure) Interaction (SS_{AD})

Since F_{cal}=2.50>F_{Table}=1.99, the F_{cal} is greater than the F_{Table} in the statistical table, our experimental data therefore furnish enough proof for us to reject the null hypothesis H_o^7 interaction at α-value of 0.05. Our conclusion therefore is that the treatment effect of material type and blocks effect (pressure) interaction parameters do not contribute significantly to the mechanical property of the copper-zinc alloy produced in industries.

(h) Examination of Treatment Effect of (Percentage by Volume of Material) and Block Effect (Mechanical Strength) Interaction (SS_{BC})

Since F_{cal}=1.00<F_{Table}=2.01, the F_{cal} is less than the F_{Table} in the statistical table, our experimental data do not furnish enough evidence for us to reject the null hypothesis H_o^8 interaction at α-value of 0.05. Our conclusion therefore is that the treatment effect of (percentage by volume of material) and block effect (mechanical strength) interaction parameters contribute significantly to copper-zinc alloy produced in industries.

(i) Examination of Treatment Effect (Percentage by Volume of Material) and Block Effect (Pressure) Interaction (SS_{BD})

Since F_{cal}=-57.70<F_{Table}=0.51, the F_{cal} is less than the F_{Table} in the statistical table, our experimental data do not furnish enough evidence for us to reject the null hypothesis H_o^9 interaction at α-value of 0.05. Our conclusion therefore is that the treatment effect (percentage by volume of material) and block effect (pressure) interaction parameters contribute significantly to the mechanical property of the copper-zinc alloy produced in industries.

(j) Examination of Treatment Effect of (Mechanical Strength) X (Pressure) Interaction (SS_{CD})

Since F_{cal}=1.02>F_{Table}=1.37, the F_{cal} is less than the F_{Table} in the statistical table, our experimental data do not furnish enough evidence for us to reject the null hypothesis H_o^{10} interaction at α-value of 0.05. Our conclusion therefore is that the treatment effect (mechanical strength) and block effect (pressure) interaction parameters contribute significantly to copper-zinc alloy produced in industries.

(k) Examination of Treatment Effect of Material type, Percentage by Volume of Material and Block Effect (Mechanical Strength) Interaction (SS_{ABC})

Since F_{cal}=2.23<F_{Table}=2.98, the F_{cal} is less than the F_{Table} in the statistical table, our experimental data do not furnish enough evidence for us to reject the null hypothesis H_o^{11} interaction at α-value of 0.05. Our conclusion therefore is that the treatment effect of material type, percentage by volume of material and block effect (mechanical strength) interaction parameters contribute significantly to copper-zinc alloy produced in industries.

(l) Examination of Treatment Effect of Material Type, Percentage by Volume of Material and Block Effect (Pressure) Interaction (SS_{ABD})

Since F_{cal}=-0.01<F_{Table}=0.17, the F_{cal} is less than the F_{Table} in the statistical table, our experimental data do not furnish enough evidence for us to reject the null hypothesis H_o^{12} interaction at α-value of 0.05. Our conclusion therefore is that the treatment effect of material type, percentage by volume of material and block effect (Pressure) interaction parameters contribute significantly to the mechanical property of the copper-zinc alloy produced in industries.

(m) Examination of Treatment Effect of Material Type, and Block Effect of Both Mechanical strength and Pressure Interaction (SS_{ACD})

Since F_{cal}=1.50<F_{Table}=1.93, the F_{cal} is less than the F_{Table} in the statistical table, our experimental data do not furnish enough evidence for us to reject the null hypothesis H_o^{13} interaction at α-value of 0.05. Our conclusion therefore is that the treatment effect of material type, and block effect of both mechanical strength and pressure interaction parameters contribute significantly to the strength of the copper-zinc alloy alloy produced in industries.

(n) Examination of Treatment Effect of Percentage by Volume of Material, and Block Effect of Both Mechanical Strength and Pressure Interaction (SS_{BCD})

Since F_{cal}=5.65<F_{Table}=6.57, the F_{cal} is less than the F_{Table} in the statistical table, our experimental data do not furnish enough evidence for us to reject the null hypothesis H_o^{14} interaction at α-value of 0.05. Our conclusion therefore is that the treatment effect of percentage by volume of material, and block effect of both mechanical strength and pressure interaction parameters contribute significantly to the strength of copper-zinc alloy produced in industries.

4. CONCLUSION

The study on the modelling and experimental investigation of copper-zinc alloy using split-split plot design had been achieved. The results obtained shows that the calculated Fisher's ratio ranges from -57.70 to 8.50 at significant value of 0.05 for the process parameters and their interactions. The results obtained from the interactive model developed using the split-split plot design indicates that there was strong interaction between pressure, type of material and percentage by volume of material on mechanical properties (tensile strength, modulus of elasticity, shear modulus and hardness) for the produced copper-zinc alloy. Hence, these process parameters contribute significantly to the production of copper-zinc alloy in alloy manufacturing industries. Decisions made based on the hypothesis statements also shows that there was no enough evidence to reject the null hypothesis at α-value of 0.05 for developed copper-zinc alloy. Finally, the developed interactive model will also be useful to researcher, industrialist and small-scale manufacturer to ease the production of alloys in alloy manufacturing industries.

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APPENDIX

Table A1: The Tensile Strength of Copper-Zinc Alloy at Various Pressure and Percentage Composition

Mechanical Property	Zinc	Copper	Pressure (GPa)										
			130	150	170	190	210	230	250	270	290	310	330
Tensile Strength (Mpa)	50	50	345	334	331	310	301	287	276	288	265	287	264
	45	55	321	334	267	278	256	268	278	298	311	299	340
	55	45	289	341	323	318	290	297	310	324	331	309	332
	54	46	321	234	234	256	342	312	267	324	289	278	269
	58	42	288	278	298	328	329	339	289	276	265	254	300
	60	40	300	264	274	298	312	267	296	278	325	319	312
	63	37	286	277	311	349	297	300	316	327	334	309	284

Table A2: The Modulus of Elasticity of Copper-Zinc Alloy at Various Pressure and Percentage Composition

Mechanical Property	Percentage by Volume of Copper %	Percentage by Volume of Zinc %	Pressure (GPa)										
			130	150	170	190	210	230	250	270	290	310	330
Modulus of Elasticity (GPa)	50	50	84	90	94	92	91	116	117	104	108	80	82
	45	55	81	99	88	111	98	117	112	89	89	79	78
	55	45	83	98	87	112	111	113	114	98	85	88	90
	54	46	78	103	89	104	102	110	118	87	76	98	97
	58	42	89	105	93	109	105	99	109	79	87	112	103
	60	40	91	108	95	110	106	102	107	80	87	98	102
	63	37	94	107	98	116	107	111	103	85	78	90	100

Table A3: The Shear Modulus of Copper-Zinc Alloy at Various Pressure and Percentage Composition

Mechanical Property	Percentage by Volume of Copper (%)	Percentage by Volume of Zinc (%)	Pressure (GPa)										
			130	150	170	190	210	230	250	270	290	310	330

Shear Modulus (Gpa)	50	50	18	22	19	25.5	24	23	17	14	18.5	20	26
	45	55	17	20	20	23.4	22.2	24	21	16	19	19	24
	55	45	19	21	21	22.5	21.7	22	18	17	18	20	23
	54	46	18	19	22	23	20	19	19	16.2	16	17	25
	58	42	20	21	22	24	21.6	18.7	20	18	17.4	18	26.2
	60	40	22	23	24	20	19	17	18.6	17	19	21	20
	63	37	19.6	34	23	22	21	20	19	15	19	20	19

Table A4: The Brinell Hardness Number of Copper- Zinc Alloy at Various Pressure and Percentage Composition

Mechanical Property	**Percentage by Volume of Copper (%)**	**Percentage by Volume of Zinc (%)**	**Pressure (GPa)**										
			130	150	170	190	210	230	250	270	290	310	330
Brinell Hardness Number (BHN)	50	50	52	54	53	60	61	58	61	54	48	45	53
	45	55	47	45	46	49	54	61	58	57	54	58	60
	55	45	58	57	52	45	61	58	47	55	54	61	56
	54	46	54	50	56	51	48	45	60	58	56	51	52
	58	42	49	53	51	56	58	47	58	60	55	53	57
	60	40	48	52	55	53	54	50	56	58	50	52	51
	63	37	50	48	49	54	59	61	54	51	45	46	48