Experimental Investigation and Optimization of Material Properties of Brass at Different Temperature Conditions Using Taguchi Technique

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Abstract. The present investigation deals with the optimization of the parameters for better formability behaviour of brass sheet metal under uniaxial isothermal Tensile Test by using Taguchi Design of Experiments (DoE). The standard L_9 (3^3) Orthogonal Array was formulated to run the experiments based on Taguchi robust design and accordingly uniaxial isothermal Tensile Test conducted at orientation (0^0, 45^0 and 90^0), temperature (300°C, 400°C, and 500 °C), and strain rate (0.001, 0.01 and 0.1 s^{-1}). Analysis of S/N ratios for Ultimate tensile strength and % elongation reported the optimum condition as orientation at level 1 (in degrees), temperature at level 1(in degree Celsius), and strain rate at level 3 (s^{-1}) and orientation at level 1 (in degrees), temperature at level 3 (in degree Celsius), and strain rate at level 1 (s^{-1}) respectively. ANOVA analysis reported the Temperature as the most significant parameter and its contribution are about 62.109% and 71.924% for ultimate tensile strength and % elongation respectively.

1 Introduction:

Sheet metal forming is one of the cutting-edge technologies for production of large variety of products in almost all sectors of industries such as aircraft, automotive, food and home appliance industries [1]. In sheet metal forming process, the blank of sheet metal is converted into a desired shape by light plastic deformation with the use of a suitable tooling. In present days high-strength material with low plasticity and difficult-to-form metals can also be formed under cold, warm and hot forming conditions [2,3]. The mechanical properties of the sheet metal are an important parameters and inadequate consideration of this parameters in the design of sheet metal forming processes leads to defective products [4,5]. Study of properties and behaviour of material under different variable conditions is utmost necessary before proceeding for actual manufacturing of the products.

Brass are substitutional alloys of copper (Cu) and zinc (Zn). As the Zn content increases in Cu, its tensile strength and wear resistance increases upto 45 wt.% and upon exceeding 45 wt.% its strength deteriorated rapidly [6]. The brass consists of 30–45 wt.% Zn mostly used in industrial application [7,8]. By adding alloy elements (Al, Sn, Ni, Fe) properties are modified and its performance can be improved [9, 10]. Brass can be classified into α brass, α + β' brass, and β' brass, and their microstructures are changes with Zn content. The strength and ductility of α brass are superior than that of pure Cu at room temperature; β' brass is hard and less tough; α + β' brass stronger than α brass and tougher than β' brass, hence its applications are wider. Moreover, the high-temperature β phase is softer than the low-temperature β' phase, which results better hot workability of α + β' brass [11]. Therefore α + β' brass selected for this study, which explores the effects of high temperature conditions on the mechanical properties of brass. When metals are subjected to plastic deformation under high-temperature, leads to dynamic recovery and dynamic recrystallization to occur [12,13]. The addition of Zn to the brass will decreases the stacking fault energy and dynamic recovery leads to dynamic recrystallization to improve the formability at high-temperature [14]. In general, dislocation motion in metals is easier with rise in temperature, causes an easier plastic deformation and more ductility. However, an intermediate-temperature brittleness phenomenon was found in Cu alloys [15]. The dual-phase brass (40 wt.% Zn) has a higher tensile strength than the single-phase brass (30 wt.% Zn) at room temperature [16].

Taguchi Design of experiment (DOE) method can optimize parameters with minimum experimental runs and reduce the time and cost of the experiments. Using this one can recognize parameters that may affect the quality of the products [17]. Analysis of variance (ANOVA) was proposed by Sir Ronald Fisher [19]. ANOVA analysis was carried out for a 5% significance level (i.e., for 95% confidence level). The main purpose of ANOVA is to find out, significant parameters which essentially influences the performance characteristics [20,21].

Therefore, uniaxial isothermal tensile test conducted and the effects of various elevated temperatures, strain rates and orientations on the mechanical properties and behaviour of the brass material were explored.

2 Taguchi Design Of Experiment

2.1 Identification of Factors and Responses

In the present study parameters identified for investigation are temperature, strain, orientation. The selected control factors and their levels are depicted in table 1.

Table 1. Control factors and their levels

Control Factors	Levels		
	1	2	3
A: Orientation	300	400	500
B: Temperature	0.1	0.01	0.001
C: Strain rate	0^0	45^0	90^0

2.2 Design of Orthogonal Array

Table 2. Formulation of L_9 (3^3) orthogonal array

Run	Test Parameters		
	Orientation (^{0}) A	Temperature (0^0) B	Strain Rate (S^{-1}) C
1	0^0	300	0.1
2	0^0	400	0.01
3	0^0	500	0.001
4	45^0	300	0.01
5	45^0	400	0.001
6	45^0	500	0.1
7	90^0	300	0.001
8	90^0	400	0.1
9	90^0	500	0.01

3. Experimental Procedure

3.1. Specimen Preparation

Tensile test specimens made of cold rolled brass sheet of 1mm thickness as per sub-sized ASTM E08/E8M-11 standard.

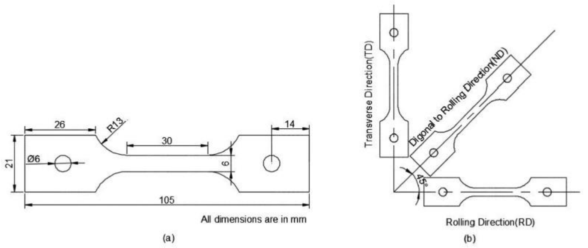

Figure1 : (a). Schematic of the tensile test specimen as per sub sized ASTM E08/E8M-11 standard and (b). Schematic of different orientations of a sheet

3.2. Experimental Set-up

The experiment was performed on BISS Electra 50 KN Servo Electric UTM under quasi-static straining condition. It is equipped with two zone split furnace, maximum 1000 ºC heating capacity with ± 3 °C accuracy, temperature of specimen was controlled through 3 thermocouples.

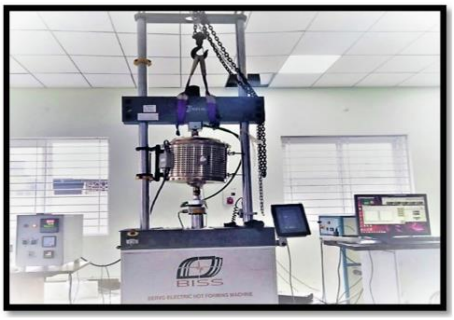

Figure 2 : Uniaxial Tensile Test Machine

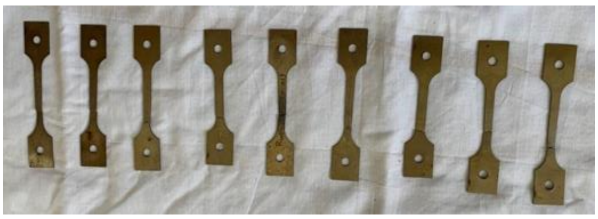

Figure 3 : Uniaxial Tensile Test Specimens in all orientation

Table 3 : Experimental result for Tensile strength

Run	Experiment Results				
	Orientation (^{0})	Temperature (0^0)	Strain Rate (S^{-1})	UTS (Mpa)	% EL
1	0^0	300	0.1	354	36
2	0^0	400	0.01	202	39
3	0^0	500	0.001	126	43
4	45^0	300	0.01	341	32
5	45^0	400	0.001	198	35
6	45^0	500	0.1	126	39
7	90^0	300	0.001	341	31
8	90^0	400	0.1	181	34
9	90^0	500	0.01	123	36

4 Analysis of Results

4.1 Analysis of S/N Ratio

Signal-to Noise Ratio (*S*/*N* ratio) analysis is an optimizing tool used for the measurement of quality

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deviation from the target value. The S/N ratio carried out in this work is executed based on the larger the better for ultimate tensile strength and % elongation using equation 1 and 2 respectively. Results are reported in table

Objective Function : Larger-the better (LTB) : It is selected when the aim is to maximize the response

$$\text{SNR} = -10\log_{10}\left[\frac{1}{n}\sum_{i=1}^{n}\left(\frac{1}{a_i^2}\right)\right] \qquad (1)$$

Where
S/N représents signal to noise ratio.
n represents number to test
a_i represents the ultimate tensile strength and % elongation values

Table 4. Computation of S/N ratio for Ultimate Tensile Strength

Expts	Parameters			S/N Ratio	
	Orientation (^{0})	Temperature (0^0)	Strain Rate (S^{-1})	UTS (Mpa)	% EL
1	0^0	300	0.1	50.98	31.12
2	0^0	400	0.01	46.10	31.82
3	0^0	500	0.001	42.00	32.66
4	45^0	300	0.01	50.65	30.10
5	45^0	400	0.001	45.93	30.88
6	45^0	500	0.1	42.00	31.82
7	90^0	300	0.001	50.65	29.82
8	90^0	400	0.1	45.15	30.62
9	90^0	500	0.01	41.79	31.12

The mean S/N ration values of each parameter for each level have been investigated and presented in table 4. It was observed that from table 5 and table 6 and also from figure 4 and figure 5 that the optimum condition for brass sheet metal in uniaxial tensile test for ultimate tensile strength and % elongation are reported as orientation at level 1 (in degrees), temperature at level 1(degree Celsius), and strain rate at level 3 (s^{-1}) and orientation at level 1 (in degrees), temperature at level 3(degree Celsius), and strain rate at level 1 (s^{-1}) respectively. From the table 5 and table 6 it very clear that rank 1 denotes that temperature is most significant and contributing factor in both the cases under uniaxial tensile test.

Table 5. Mean of S/N Ratio for Ultimate Tensile Strength

Level	Orientation	Temperature	Strain Rate
1	**46.36**	**50.76**	**46.20**
2	46.20	45.73	46.19
3	45.87	41.94	46.05
Delta	0.50	8.83	0.15
Rank	2	1	3

Table 6. Mean of S/N Ratio for % Elongation

Level	Orientation	Temperature	Strain Rate
1	**31.87**	30.35	31.13
2	30.94	31.11	31.02
3	30.53	**31.87**	**31.19**
Delta	1.34	1.52	0.18
Rank	2	1	3

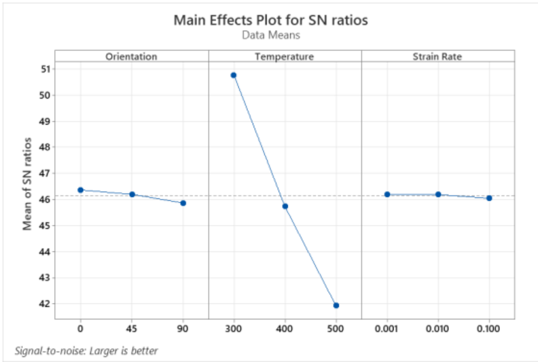

Figure 4 : Main effects plots for SN ratio for ultimate tensile strength

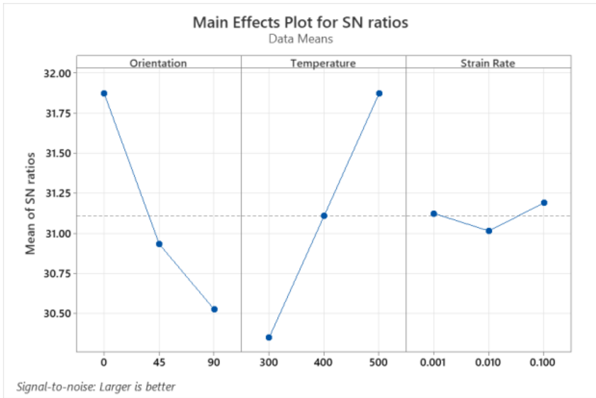

Figure 5 : Main effects plots for SN ratio for % elongation

4.2 Development of mathematical model with regression analysis

Using the experimental response, mathematical regression model has been developed in MINITAB 19 software. The regression model for Ultimate Tensile Strength and % Elongation reported as equation 2, equation 3. For all the cases the R-sq and R-sq(adj) are reported. R-sq is the wellness response of regression model usually lie in between 0% to 100%. 0% denotes a model that does not states any of the variation in the response variable around its mean and 100% denotes a model that states all of the variation in the response variable around its mean. Generally, larger the R-sq, better the regression model fits. In the present for all cases the regression models are closer to 100% hence one can say that these models having better regression fit. From figure 6 depicts the different strain rates for different shaded areas (i.e. contour plot of Strain Rate Vs Temperature, Orientation). Figure 7 represents the surface plot of Strain Rate Vs Temperature, Orientation.

Regression Equation for ultimate tensile strength

UTS = 561 + 1.33 Orientation – 0.890 Temperature
+ 581 Strain Rate – 0.00253 Orientation* Temperature – 12.50 Orientation*Strain Rate
+ 0.09 Temperature * Strain Rate (2)

R-sq = 98.54% R-sq(adj) = 94.15%

Regression Equation for % elongation

$$\% EL = 18.63 + 0.0475\ Orientation + 0.04895\ Temperature + 69.6\ Strain\ Rate - 0.000256\ Orientation*Temperature - 0.064\ Orientation*Strain\ Rate - 0.1420\ Temperature*Strain\ Rate \quad (3)$$

R-sq = 98.93% R-sq(adj) = 95.73%

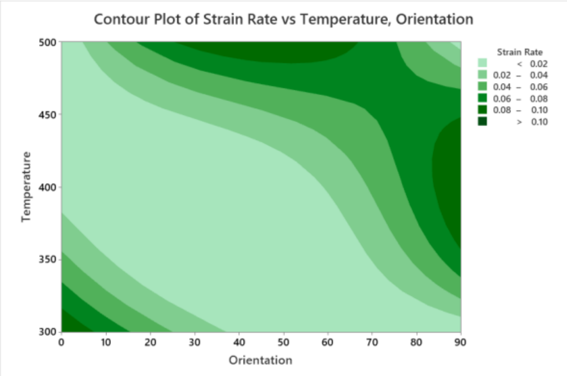

Figure 6 : Contour plot of strain rate vs temperature & orientation

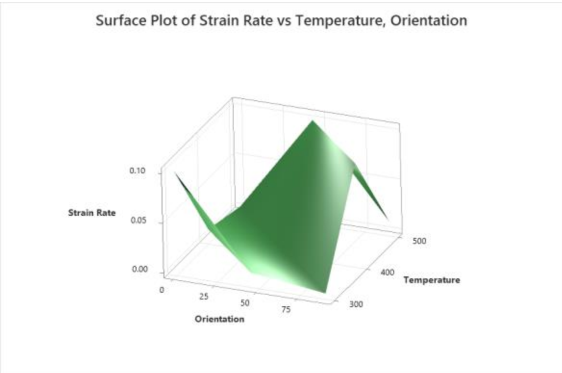

Figure 7 : Surface plot of strain rate vs temperature & orientation

3 Analysis of variance (ANOVA)

Analysis of variance developed by Sir Ronald Fisher [17]. In the present paper it applied to evaluate the significance level of 5%, at 95% confidence level.The primary aim of ANOVA is to investigate the parameter that significantly influence the response variables [19].

In this paper ANOVA was carried out for all the cases and shown in table 7 and table 8. From ANOVA analysis as shown in table 7 and table 8 and also from figure 8 and figure 9 it is clear that temperature is most significant parameter and its contribution are about 62.109% and 71.924%. Figure 10 and figure 11 depicts the goodness fitting of normal probability plot for ultimate tensile strength and % elongation under the uniaxial tensile test.

Table 7. Analysis of Variance (ANOVA) for Ultimate tensile strength

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% Cont
Regression	6	75511.9	12585.3	22.47	0.043	
Orientation	1	363	363	0.65	0.505	3.69
Temperature	1	6110.1	6110.1	10.91	0.081	62.109
Strain Rate	1	131.2	131.2	0.23	0.676	1.334
Orientation* Temperature	1	261.9	261.9	0.47	0.565	2.662
Orientation* Strain Rate	1	2410.9	2410.9	4.3	0.174	24.507
Temperature* Strain Rate	1	0.6	0.6	0	0.977	0.006
Error	2	1120.1	560			5.692
Total	8	76632	9837.7			100

Table 8. Analysis of Variance (ANOVA) for % Elongation

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% Cont
Regression	6	111.683	18.6138	30.87	0.032	
Orientation	1	0.459	0.4587	0.76	0.475	1.783
Temperature	1	18.499	18.4994	30.68	0.031	71.924
Strain Rate	1	1.885	1.8846	3.13	0.219	7.327
Orientation* Temperature	1	2.677	2.6771	4.44	0.17	10.408
Orientation* Strain Rate	1	0.062	0.0624	0.1	0.778	0.243
Temperature* Strain Rate	1	1.536	1.5355	2.55	0.252	5.970
Error	2	1.206	0.603			2.344
Total	8	112.889	25.7207			100

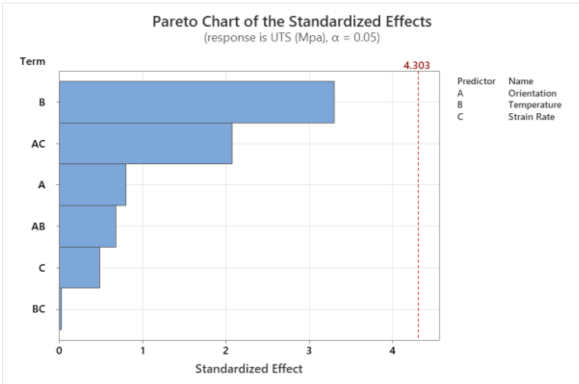

Figure 8 : Pareto chart of the standardized effects for ultimate tensile strength

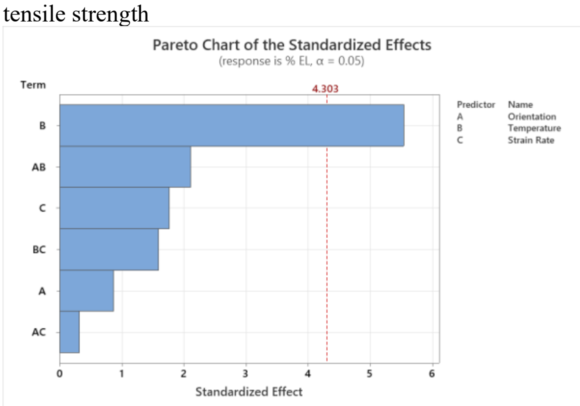

Figure 9 : Pareto chart of the standardized effects for % elongation

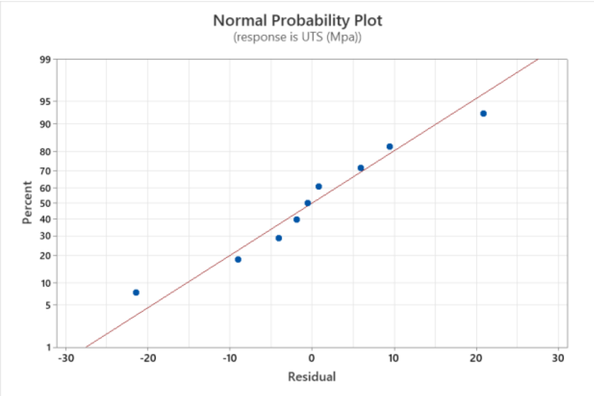

Figure 10 : Normal probability plots for ultimate tensile strength

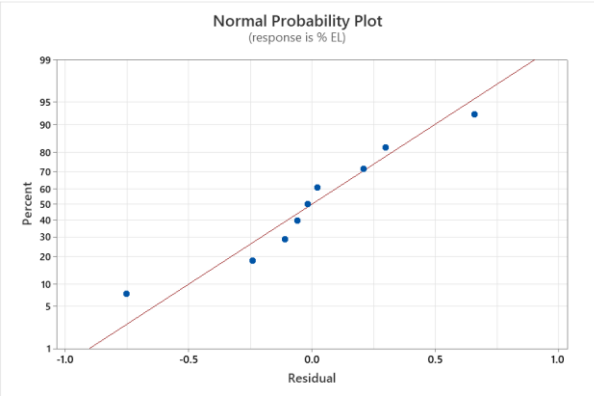

Figure 11 : Normal probability plots for % elongation

5 Confirmation Experiment

Taguchi recommended the Confirmation Test essentially to verify the test results [26]. The ideal dimension of the parameters is determined using Eq. (4)

$$Y = Y_m + \sum_{i=0}^{q} Y_i - Y_m \qquad (4)$$

Where Y_m is the total mean Signal- to - Noise ratio, Y_i is the mean optimum level and 'q' is the number of significant parameters. The main purpose of conducting the confirmation test is to assist the optimum parameter conditions that were proposed by the investigation which compared with the predicted value. Table 9 reported the optimal parameter settings of predicted and experimental values for obtaining the best result (i.e. Ultumate tensile strength and % Elongation)

Table 9 : Confirmation Experiment

	Optimum parameter for Ultimate Tensile Strength		**Optimum parameter for % Elongation**	
	Prediction	**Experiment**	**Prediction**	**Experiment**
Level	$A_1B_1C_3$	$A_1B_1C_3$	$A_1B_3C_1$	$A_1B_3C_1$
Response	355	358	44	45
SNR	51.03	52.01	32.71	32.98

6 Conclusions

Present paper deals with the optimization (maximization) of responses (i.e., ultimate tensile strength and % elongation) of brass under various temperature conditions of uniaxial tensile test. Taguchi design method provides the efficient optimum conditions for uniaxial tensile test. The following are the important concluding remarks obtained from the work.

1. The optimum conditions obtained for ultimate tensile strength for uniaxial tensile test was orientation level 1(0^0), temperature level 1 (300^0) and strain rate level 3 (0. 001 s^{-1}).

2. The optimum conditions obtained for and % elongation for uniaxial tensile test was orientation level 1(0^0), temperature level 3 (500^0) and strain rate level 3 (0. 1 S^{-1}).

3. The mathematical model generated for ultimate tensile strength was R-sq = 98.54%, R-sq(adj) = 94.15% and % elongation was R-sq = 98.93%, R-sq(adj) = 95.73% under tensile test having better regression fit as it closer 100%.

4. From the confirmation experiment, test results have been verified and found that predicted and experimental results are very close and hence optimal parameter settings are recommended for sheet metal manufacturing applications in industries.

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