STATISTICAL ANALYSIS FOR SLIDING WEAR PARAMETERS OF BRONZE BASED COMPOSITES

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Abstract:

In tribological industries metal matrix composites are now being more commonly used because of their inherent properties such as high stiffness, high strength, high toughness etc. The effect on tribological properties of cobalt-reinforced bronze-based metal matrix composites was investigated. In a bronze matrix, cobalt metal powders of 40μm particle size were reinforced to yield composite samples of ratios 2, 4 and 6 percent by means of stir casting process. As per ASTM G99, the manufactured composite specimens were subjected to sliding wear tests using pin-on - disc system. The sliding wear experiments were carried out by following the Taguchi methodology and the variance approach analysis was used to assess the effect of wear factors such as applied load, sliding speed, material composition and sliding distance on wear resistance of manufactured composites. In addition, multiple linear regression analysis and signal-to-noise ratio were used to analyze bronze based metal matrix composite wear behaviour. The injection of cobalt metal powders into bronze matrix material as reinforcement material increases the tribological characteristics.

Keywords: **Bronze, Cobalt, Stir Casting, Wear, Analysis of Variance, Taguchi Method.**

1. INTRODUCTION

Engineering applications need metal matrix composites (MMCs) due to their superior physical and mechanical properties. Current focus of research is on MMCs due to their scientific and technological benefits. MMCs with particulates as reinforcement are comparatively less expensive and have isotropic properties when equated to fiber-reinforced MMCs. Boron, silicon nitride, boron nitride, silicon carbide, titanium carbide, and alumina are available as particle reinforcements, but research is focused on development of cobalt (Co) reinforcement. Co-reinforced composites are favored as they have superior refractoriness and high resistance to abrasion in comparison with composites reinforced with different category of reinforcements. Dyachkova et al. [1] found improvement in mechanical and tribological properties of Cu-Sn bronze by adding correct percentage of alumina additive. Miguel et al. [2] also found improvement in microhardness, adhesion strength and tribological behavior of the aluminum bronze with alumina additive. Paul et al. [3] observed improvement in hardness as weight percentage of Sn increases in Cu-Sn bronze alloys. Kulasa et al. [4] examined microstructure and tribological properties of tin bronze-graphite composites with titanium to the metal matrix in order to improve wettability of the graphite particles, lowest average value of the coefficient of friction was found with the CuSn10/graphite 45 µm composite with 0.4 % Ti**.** Gupta et al. [5] developed and analyzed the mechanical properties of industrial aluminum-bronze with rice husk ash metal matrix composite, maximum hardness and tensile strength was found with increase in rice husk ash composition. Jin et al. [6] examined tribological properties of bronze–Cr–Ag composites, found that that the additions of Cr and Ag improve the wear resistance and lubricating properties of the composites simultaneously. Gul et al. [7] examined effect of nickel coated nano SiC particles in bronze matrix, found that the addition of nano SiC increases the performance of the bronze matrix with respect to the microhardness and sliding wear.

Above literature survey indicates that little experimental work has been published so far about influence due to addition of Co particle and their weight fraction on microstructure of bronze alloy, fabricated by stir casting process. This research is carried out to analyse microstructure of cobalt reinforced bronze composites and to investigate tribological properties such as sliding wear resistance due to adding of cobalt content with proportions of 2, 4 and 6 weight percent in bronze matrix using Taguchi experiment design. The variance analysis was used to find the percentage of impact of different variables on the composites dry sliding wear. These composites would be used in automobile, railway, shipping and aerospace applications.

2. TAGUCHI TECHNIQUE

Taguchi technique is an important tool for developing high quality systems. It provides a simple effective and systematic method for optimizing efficiency, cost effective and quality designs. The technique is useful when qualitative and discrete design criteria are applied. Taguchi parameter design can improve performance characteristics by setting design parameters and reducing device output sensitivity to variance source. This technique is a multi-step method that follows a certain sequence for the tests to provide a better understanding of the output of a product or process. This experiment process design consisted of three main steps: the preparation step, the step of conducting and the step of interpretation of the results. Variance analysis is a statistical method that is based on a minimally square approach. The evaluation of the experimental outcomes is focused on the analysis of the mean and the variance analysis.

3. EXPERIMENTATION

3.1 Materials

In present work bronze ingots made of compositions 90% copper and 10% tin were used as matrix material and cobalt metal powder of 40µm size were used as reinforcement material.

3.2 Fabrication Technique

Bronze ingots were melted at a temperature of 950 ^{0}C in 6kW electrical resistance furnace. Treatment for degassing was achieved using tablets with Hexachloroethane (C_2Cl_6). Cobalt metal powder (2% of the weight of bronze) preheated to 300 ^{0}C to remove any residual moisture was then slowly added to vortex of the stirred liquid bronze at a temperature of 1050 ^{0}C and stirring at a steady speed of 300rpm was maintained till a consistent molten metal composite was obtained. The high temperature liquid metal composite was poured into preheated (300 ^{0}C) cast iron moulds to obtain the required specimens. The same procedure was followed to obtain the different percentage of weight - 4% & 6%. Castings that are taken out from the cast iron moulds are machined as per ASTM standards in order to prepare specimens for wear testing. Table 1 indicates fabricated composite compositions.

Table 1 Fabricated composite compositions

Material composition	Bronze (Wt.%)	Cobalt (Wt.%)
Composite 1	98	2
Composite 2	96	4
Composite 3	94	6

3.3. Design of Experiments

The experiments were performed in conjunction with the standard orthogonal array. In this inquiry, orthogonal arrays of L_{27} were identified. The factors for wear were selected for the experiment are i)Material composition, ii) Load, iii) Speed and iv) Distance to sliding. The reaction variable chosen was the loss of material. Table 2, shows process factors at three levels, with their values. The results of the wear tests were subjected to variance analysis.

Table 2 Process factors with their values at three levels

Control Factors	Units	Level 1	Level 2	Level 3
M: Material composition	Wt.%	2	4	6
L: Load	kg	1	2	3
S: Speed	Rpm	200	400	600
D: Sliding distance	Meter	1000	2000	3000

3.4 Wear Test

To investigate the composite 's dry sliding wear characteristics as per ASTM G99, a pin - on - disc test apparatus has been used. The wear specimen was initially cleaned with acetone and dried with a diameter of 8mm and a height of 25mm. After that first the specimen's initial weight was measured in a single pan electronic weighing machine with a minimum count of 0.0001g. During the test the pin was pressed by applying the load against the counterpart rotating against EN32 steel disc with a hardness of 65HR_C. The specimens were removed after running through a fixed sliding distance, cleaned with acetone, dried, and weighed to determine the weight loss due to wear. The weight difference measured before and after test gives the composite specimen dry sliding wear. The composites wear was studied as a function of the sliding distance, the load applied and the sliding speed.

4. RESULTS & DISCUSSIONS

4.1. Microstructure Characterization:

The shape, density, size and distribution of reinforcing particles have a major impact on the properties of particulate composites. Using JEOL JSMT320 scanning electron microscopy (SEM), microstructural analysis of the experimental composites was performed conventionally on ground and polished samples. SEM analysis was conducted using a large -area backscattered electron detector to create an image in the as-polished samples.

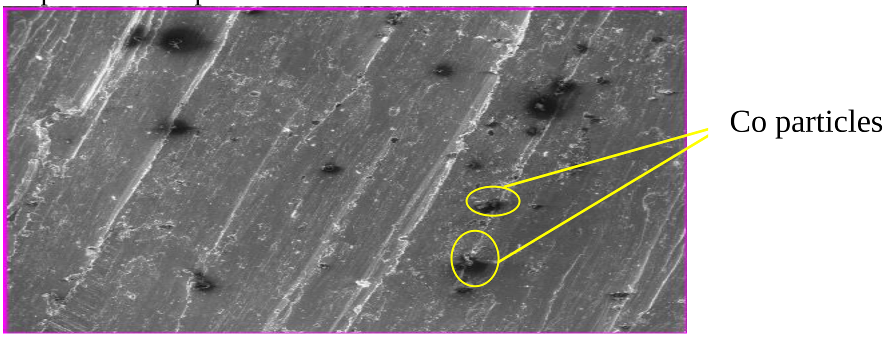


Fig. 1: Microstructure of Bronze - 2 wt.% Co

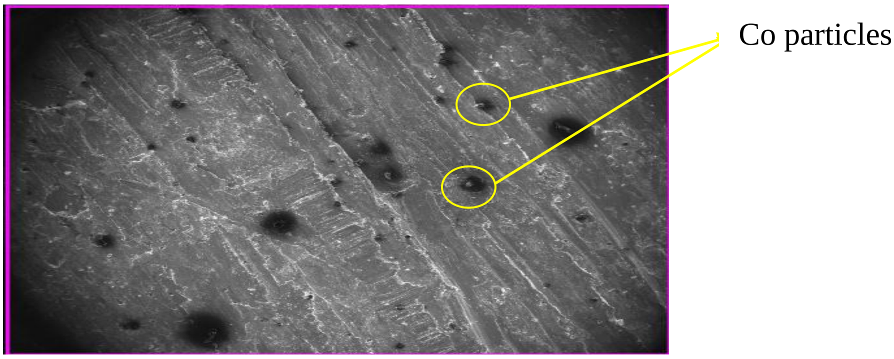


Fig. 2: Microstructure of Bronze - 4 wt.% Co

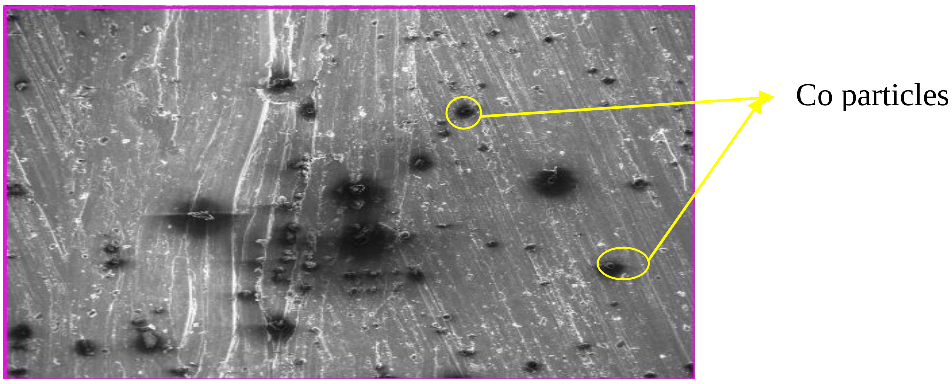


Fig. 3: Microstructure of Bronze - 6 wt.% Co

Microstructure of bronze containing 2, 4, and 6 wt.% Co exhibited consistent dispersal of Co particles shown in Fig. 1-3. The darker particles are cobalt and lighter ones are bronze. These microstructures approve that Co reinforcement dispersal is spatially consistent. This is necessary for isotropic properties. Distribution of Co particles was relatively uniform, showing few clustering. However, any cluster that is present may reduce strength and ductility by initiating localized damage. In this respect, such clusters may be thought of as areas of prospective destruction that occur earlier to loading. It is seen that any such clustering is more probable to happen in composites reinforced with fine particulates. Clearly, if optimized performance is required, then any such area of bunching must be minimized. [8 -12]

4.2. Statistical Analysis:

The experiments were conducted in order to relate the effect of material composition (M), applied load (L), sliding speed (S), and sliding distance (D) of the composites under analysis with dry sliding wear. The dry sliding wear results for different combinations of factors in terms of material loss, signal to noise ratio and means were obtained and shown in Table 3 when performing the experiments according to the L_{27} orthogonal array. Table 4 shows the SN ratios response obtained for this method, this table clearly shows that the sliding speed is a major factor on material loss due to sliding wear followed by load, sliding distance and material composition. The objective of Analysis of variance is to investigate the design factors affects the wear characteristic significantly. The optimum combinations of the process parameters are forecast based on ANOVA. This study is done for 5% significance level (i.e. 95% confidence level).Table 5 displays the findings of the ANOVA study. Fig. 4 the impact of control factors on material loss graphically and optimal conditions for material loss due to sliding wear are material composition 2% (level 1), load 3 kg (level 3), speed 600 rpm (level 3) and sliding distance 3000 m (level 3). The last column of the ANOVA cobalt-reinforced bronze-based composite analysis (Table 5) displays the percentage contribution (P) of each element to the total variance indicating their degree of impact on the outcome. It can be observed from Table 5 that the sliding speed (P = 67.97%), applied load (P = 20.73%), sliding distance (P = 1.37%) and material composition (P = 1.06%). The pooled error is 8.84%.

Table 3 Taguchi L_{27} Orthogonal Array result for material loss

Expt. No.	Material composition (M) in Wt.%	Load (L) in kg	Speed (S) in rpm	Sliding distance (D) in meter	W1 -W2 in grams	SN Ratio (dB)	Mean
1	2	1	200	1000	0.0021	53.55561	0.0021
2	2	1	400	2000	0.0053	45.51448	0.0053
3	2	1	600	3000	0.0192	34.33398	0.0192
4	2	2	200	2000	0.0069	43.22302	0.0069
5	2	2	400	3000	0.0172	35.28943	0.0172
6	2	2	600	1000	0.0281	31.02587	0.0281
7	2	3	200	3000	0.0118	38.56236	0.0118
8	2	3	400	1000	0.0105	39.57621	0.0105
9	2	3	600	2000	0.0394	28.09008	0.0394
10	4	1	200	1000	0.0019	54.42493	0.0019
11	4	1	400	2000	0.0032	49.897	0.0032
12	4	1	600	3000	0.0165	35.65032	0.0165
13	4	2	200	2000	0.0058	44.73144	0.0058
14	4	2	400	3000	0.0164	35.70312	0.0164
15	4	2	600	1000	0.0265	31.53508	0.0265
16	4	3	200	3000	0.0105	39.57621	0.0105
17	4	3	400	1000	0.0097	40.26457	0.0097
18	4	3	600	2000	0.0372	28.58914	0.0372
19	6	1	200	1000	0.0012	58.41638	0.0012
20	6	1	400	2000	0.0027	51.37272	0.0027
21	6	1	600	3000	0.0142	36.95423	0.0142
22	6	2	200	2000	0.0042	47.53501	0.0042
23	6	2	400	3000	0.0143	36.89328	0.0143
24	6	2	600	1000	0.0245	32.21668	0.0245

25	6	3	200	3000	0.0098	40.17548	0.0098
26	6	3	400	1000	0.0082	41.72372	0.0082
27	6	3	600	2000	0.0363	28.80187	0.0363

Table 4 Response table for SN ratios for material loss (Smaller is Better)

Level	Material composition (M)	Load (L)	Speed (S)	Sliding distance (D)
1	38.30	46.68	46.69	42.53
2	40.04	37.57	41.80	40.86
3	41.57	36.15	31.91	37.02
Delta	2.77	10.53	14.78	5.51
Rank	4	2	1	3

Table 5 ANOVA for material loss

Source	DF	Adj SS	Adj MS	F - Value	P - Value	P (%)
M	2	0.000035	0.000018	1.09	0.358	1.06
L	2	0.000680	0.000340	21.12	0.000	20.73
S	2	0.002229	0.001114	69.22	0.000	67.97
D	2	0.000045	0.000023	1.40	0.271	1.37
Error	18	0.000290	0.000016			8.84
Total	26	0.003279				100

Model Summary:

R-sq = 91.16 %

R-sq(adj) = 87.23 %

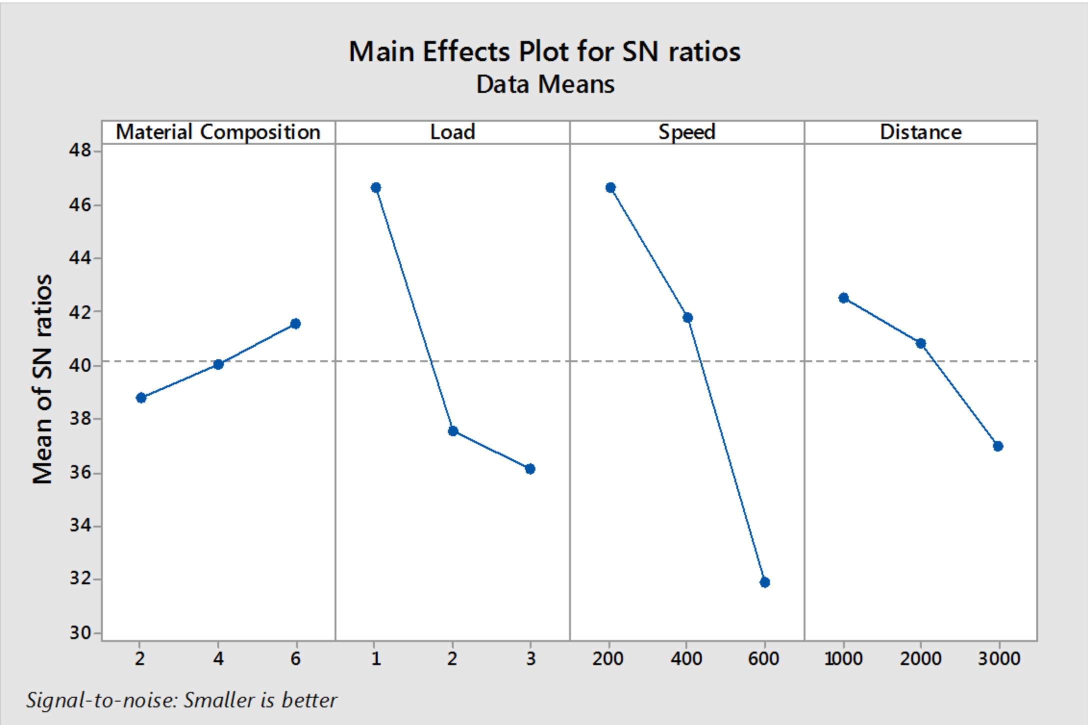


Fig. 4: Main effects graph for SN ratios – Material loss

4.3. Multiple linear regression models:

The multiple linear regression models were developed using the statistic tool MINITAB 17. This model obtained the relationship between an independent variable and the response variable in the form of linear equation from the observed results. The regression equation developed for loss of material is

$$W1 - W2 = -0.01767 - 0.000697\ M + 0.00595\ L + 0.000052\ S + 0.000001\ D$$

Fig. 5 displays the plot of standard residuals with probability. From the figure the data points are similar to the usual line of likelihood. It shows the residuals are usually distributed around the line and the model is ideally suited for predicting material loss due to sliding wear.

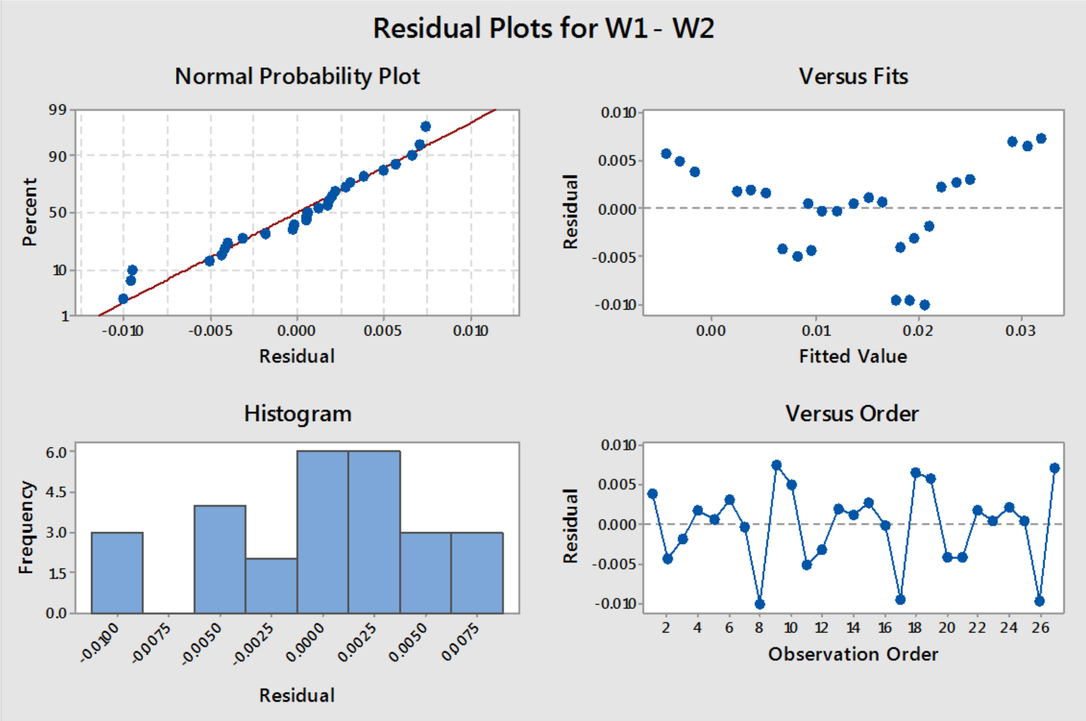
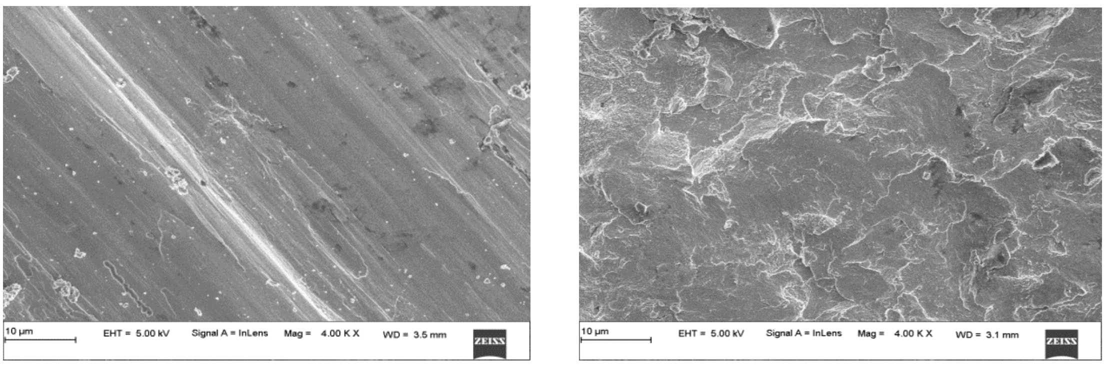


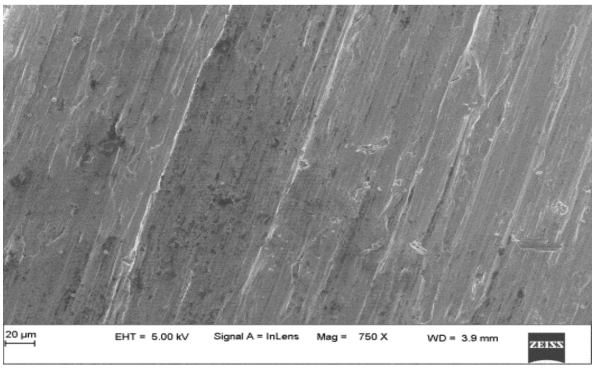
Fig. 5: Normal probability graph of residuals and fits

4.4. Wear Mechanism:

Under the influence of load applied, the asperities of pin and counter face that are in contact are subject to relative motion. Initially both surfaces are associated with a large number of sharp asperities, and at these points mainly there is contact between them. The asperities in each surface come into contact with each other under the influence of applied load and speed and are either plastically deformed or remain in elastic contact. Since the asperities are very sharp in nature, the effective stress on these sharp points may be greater than the elastic stress, and then all these sharp asperities will be plastically deformed to their contact points except for the partly projected reinforcing points. Over the course of operation, the plastically deformed surface fills the valley of the material both in pin and counterface and there is the risk of breaking a few asperities on both surfaces leading to very fine debris. [13 – 21] Fig 6 (a – c) represent the microstructures of worn surfaces of bronze - 2wt. % Co, bronze - 4wt. % Co and bronze - 6wt. % Co composites respectively. As the sliding distance increases the loss of wear volume which can be due to the ploughing capacity of the broken particles between the pin and the counter face will not decrease as the sliding distance increases [22]. The loss of volume from the dry sliding wear increases with increased load. In compression the cobalt particles are very heavy than the tension. This impacts the ability of broken particles to pass between pin and counter face. Also the removal of material from the pin's surface increases with gradual load [23].



(a) (b)



(c)

Fig. 6: The SEM micrographs of worn surfaces of (a) Bronze - 2wt. % Co, (b) Bronze - 4wt. % Co and (c) Bronze - 6wt. % Co composites at load = 3kg, speed = 600rpm and sliding distance =3000m.

5. CONFIRMATION TEST

The results obtained were confirmed via the confirmation examination. Table 6 displays the experimental parameters used for the research. Table 7 reports the results of the validation test and the relation between the experimental values and the estimated values established from the regression model. The experimental value of material loss ranges between 3.04% and 6.22% from the regression equation. It was found that the material loss obtained from the regression model and experiments matched with least error.

Table 6 Confirmation experiment for material loss

Expt. No	Material composition (M) in Wt.%	Load (L) in kg	Speed (S) in rpm	Sliding distance (D) in meter
1	2	2	500	1500
2	4	2	500	1500
3	6	2	500	1500

Table 7 Result of confirmation experiment for material loss and their comparison with regression model.

Expt. No	Expt. material loss in grams	Reg. model eqn. material loss in grams	% Error
1	0.0211	0.020336	3.62
2	0.0202	0.018942	6.22
3	0.0181	0.017548	3.04

6. CONCLUSIONS

The composition of 2, 4 & 6 weight % of cobalt reinforced bronze basedcomposites were produced through stir casting technique. The tribological properties of the samples were evaluated. The following conclusions are made from the study.

1 Stir casting technique was successfully adopted in the preparation of cobalt reinforced bronze based composites.
2 Increase in wear resistance of cobalt reinforced bronze composites with rise in weight percentage of Co particles.Maximum improvement in wear resistance was seen with the addition of 6wt.% of cobalt reinforcement in bronze matrix.
3 Sliding speed (67.97%) has the more impact on the material loss of bronze based composite followed by applied load (20.73%), sliding distance (1.37%) and material composition (1.06%) under dry sliding wear conditions.
4 The equation of regression developed for cobalt reinforced bronze based composite was used to predict material loss with good accuracy for the intermediate conditions.
5 The confirmation test results showed the least error; thus, Taguchi technique experiment design is used successfully to research the tribological behaviour of bronze-based composites.

Conflict of Interest:

The authors declare no conflict of interest.

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