Nat. Volatiles & Essent. Oils, 2021; 8(6): 360-369

NVEO
Natural Volatiles & Essential Oils

Wear Behavior Analysis On Cu-Al-Be Shape Memory Alloy Through Taguchi Approach

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Abstract:

The preparation of Cu-Al-Be SMA's is the focus of this experimental work. The goal was to economically prepare them using Gravity die casting and an induction furnace. The martensitic phase was obtained by subjecting the casts to a suitable thermal procedure. The shape memory effect and hardness were evaluated using the Bend test and Vickers hardness equipment, respectively. We Observed that an increase in the small addition of Be increases the hardness of the alloy. After confirmation of SME, the wear test of Cu-Al-Be SMA's was performed using pin on disc equipment. The three discrete parameters, sliding speed, applied load, and sliding distance, were analyzed using the Taguchi technique. The experiment plan is generated by Taguchi's method, and based on the L_{27} orthogonal array, the experiments were conducted. ANOVA and regression models were used to find the optimum wear characteristics for three discrete parameters: sliding distance, load, and speed. The "smaller the best" is chosen, finally evaluated dry sliding wear resistance, and performed validation by experimental findings. SEM is used to study the morphology of worn surfaces and their wear mechanisms. Microstructural studies showed that adhesive, abrasive, brinelling, and surface fatigue wear mechanisms contribute to this SMA alloy wear.

Keywords: ANOVA,Shape Memory Alloy, Taguchi approach, Wear

Introduction

SMA's are a category of metallic materials exhibiting the potential to revert to any previously defined shape or scale when exposed to the required thermal procedure. Generally, these materials deformed plastically at any relatively low temperature. Before the deformation, they can revert to their shape following exposure to some higher temperature [1]. Materials that only show shape memory when heated are recognized as possessing a one-way shape memory. On re-cooling, certain materials often experience a shift in shape. These materials provide a memory of the two-way form. While many alloys exhibit the form memory effect, only those that can recover substantial strain or generate significant force when reshaped are commercially important. Nickel-titanium alloys and copper-base alloys such as Cu-Zn-Al and Cu-Al-Ni are some shape memory alloys [2]. In a martensitic transition, a shape memory alloy may deform below the transformation temperature via twinning. The distortion is reversed when the twin configuration returns to the parent phase [3].

SMA's wear behavior is related to the martensitic thermo-elastic transformation. Until undergoing plastic deformation and subsequent cracks triggered through wear, these alloys can consume a significant amount of energy due to this transformation. This study identified the influence of sliding speed and applied load on the dry wear action of Cu-Zn-Al alloys due to the Ms transition temperature at different sliding speeds and applied loads [4]. The alloy's weight loss and friction coefficient displayed linear and exponential relationships as a load function. However, there was an exponential connection and no direct link regarding the alloy's weight loss and friction coefficient [5].

Taguchi approach

The Taguchi approach is a controlling tool for designing a process based on the OA- Orthogonal Array. ANOVA is used to minimize the number of experiments and also efficiently improve the processes. This investigation considers the response value of wear rate, and the parameters are %reinforcement, sliding velocity, sliding distance. This study evaluates the design of experiments of L9orthogonal array [7]. The step by step procedure performed in the Taguchi approaches is given below;

Step 1: Parameter Selection and identification of control factors
Step 2: Identification of the level of each factor
Step 3: Selection of an Orthogonal Array (OA) experiment
Step 4: Execution of matrix experiment by assigning control factor to columns of OA
Step 5: Data analysis to predict the optimal value and evaluate the performance
Step 6: Verification and confirmation of analyzed data

Experimental Work

The Cu-Al-Be Shape memory alloy was used for this investigation. The 27 samples of 10 mm diameter and 30 mm length workpieces are considered in this study. All the samples are cleaned well in the Acetone before conducting the wear test.

Table 1: chemical composition of Cu-Al-Be Shape-memory Alloy

Alloy ID	Chemical Composition, wt%		
	Cu	Al	Be
CAB1	88.38	11.20	0.42
CAB2	88.05	11.50	0.45
CAB3	87.83	11.70	0.47

The wear analysis of Cu-Al-Be Shape memory alloy is examined by designing experiments Taguchi’s L27 orthogonal array. The process parameters are to be considered for this wear study experiment are the Sliding speed(rpm), Applied Load(N), Sliding distance(m), and Material (Wt.%), which are allotted with three different levels are presented in Table 2. In addition, the various constitution of the materials are shown in the Cu-Al-Be Shape memory alloy was illustrated in Table1.

Table 2: Process parameters and their levels

Sl. No	Factor	Unit	Level1	Level2	Level3
1	Sliding speed	rpm	40	80	120
2	Applied Load	N	5	10	15
3	Sliding distance	m	500	1000	1500
4	Material	Wt.%	CAB1	CAB2	CAB3

The model of the wear test equipment as DUCOM TR 20- LE, the parameters of different sliding velocity likes as 40, 80, and 120 rpm, sliding distance as 500, 1000, and 1500 m, and applied load as 5N, 15N, and 20 N. The specimens were cleaned well with fine emery sheet and further it is immersed in kerosene. Weights of sample sets were noted before and after wear; it calculates the wear loss or weight loss.

Results and Discussion

Microstructural Examination

The samples were cut with a low-speed diamond saw and mechanically polished in emery sheets 200-2000 grid-scale, then cloth polished using 0.1 mm alumina paste. Samples were etched into $2gk_2Cr_2O_7 - 8mlH_2SO_4 - 2mlHCl - 100mlH_2O$ etchant solution and studied these samples were at 50X magnification under an upright optical microscope (Olympus-Japan).

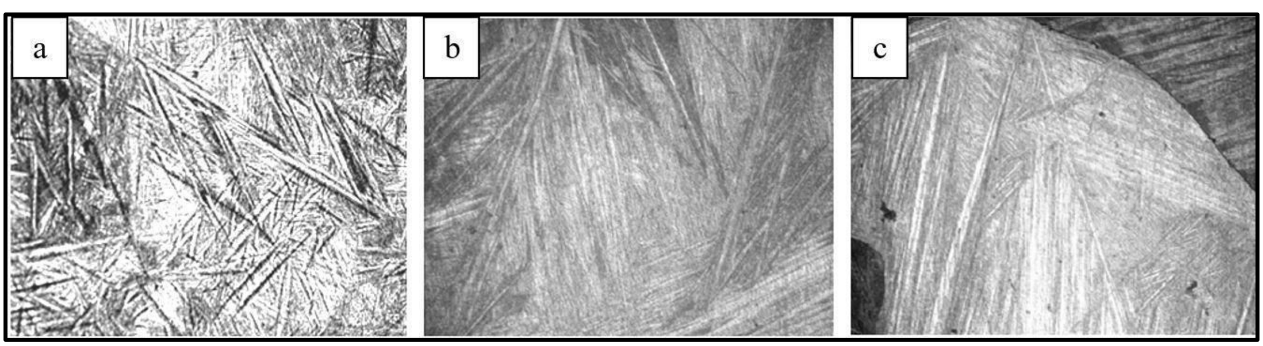


Fig. 1. Martensite observed for the composition (a) CAB1,(b) CAB2 and (c) CAB3

Given the initial structure, the martensite surfaces had highly distinct crystal orientations. Martensitic transformation also leaves characteristic surface markings. Fig. 1(a), (b), and (c) indicate the presence of lathe martensite; the Be plays an important role in increasing the percentage of martensite, which majorly affects the wear rate. The wear rate decreases with an increase in martensitic structure.

In thisexperiment, 27 trials were carried out; the wear rate and S/N ratio values were determined and were presented in Table 3. Table 4 and Fig. 2 showed the difference between the acceptable levels between the largest to smallest mean and S/N ratio values [13]. It is information which parameter has the highest delta value is measured as a greater influence on the response of wear rate (Fig. 2). Figs. Three illustrated the main effect plot for the mean and S/N ratio of the wear, respectively [14–16]. Figure 3 showed the sliding distance value would moderately change the wear rate with an increase since the sliding distance was a major influencing factor. The plot shows (See Fig. 3) that all the points have lied on the mean value since the selected parameters of these experiments were a good one. ANOVA is mainly used to evaluate the factors among their significances in their percentage contribution to the response, like wear rate in Table 4. It is primarily conducted by the significant level of 5% and 95% confidence level with highly accurate results [17]. The test outcomes were examined using ANOVA to explore the impact of wear variables, specifically: sliding speed, load & sliding distance. These variables majorly affect the SMA performance. By conducting ANOVA [9], it's very well may choose independent variable prevails on another & rate commitment with specific free variable. The sliding distance was found to have the greater impact (Pr=60.44 %) on weight loss for Cu-Al-Be Shape Memory Alloys from Table 4. Therefore, sliding time, accompanied by applied loads, is a significant control factor considered during the wear process (P=24.26 %) and sliding velocity (P=5.15 %). The interaction terms have little to no impact on weight loss & just 13.04 % of the pooled errors. The variance & Signal Noise ratio research concludes that sliding distance contributes most to weight loss, followed by load & sliding speed.

Table 3: Summary of wear test with S/N ratios of Cu-Al-Be Shape Memory Alloy

Exp. No.	Sliding speed, S(rpm)	Load, L (N)	Sliding distance, D (m)	Material, CAB (Wt %)	Weight loss, WL (gm)	SNRA
1	40	5	500	CAB1	0.0020	53.9794
2	40	5	1000	CAB2	0.0045	46.9357
3	40	5	1500	CAB3	0.0065	43.7417
4	40	10	500	CAB2	0.0045	46.9357
5	40	10	1000	CAB3	0.0074	42.6154
6	40	10	1500	CAB1	0.0111	39.0935
7	40	15	500	CAB3	0.0043	47.3306
8	40	15	1000	CAB1	0.0104	39.6593
9	40	15	1500	CAB2	0.0136	37.4573
10	80	5	500	CAB2	0.0005	66.098
11	80	5	1000	CAB3	0.0035	49.1186
12	80	5	1500	CAB1	0.0064	43.8764
13	80	10	500	CAB3	0.0020	53.9794
14	80	10	1000	CAB1	0.0052	45.6799

15	80	10	1500	CAB2	0.0072	42.8534
16	80	15	500	CAB1	0.0037	48.636
17	80	15	1000	CAB2	0.0078	42.1581
18	80	15	1500	CAB3	0.0098	40.1755
19	120	5	500	CAB3	0.0007	63.0206
20	120	5	1000	CAB1	0.0032	49.897
21	120	5	1500	CAB2	0.0076	42.3837
22	120	10	500	CAB1	0.0045	46.9357
23	120	10	1000	CAB2	0.0058	44.6658
24	120	10	1500	CAB3	0.0099	40.0654
25	120	15	500	CAB2	0.0030	50.4576
26	120	15	1000	CAB3	0.0060	44.437
27	120	15	1500	CAB1	0.0141	37.056

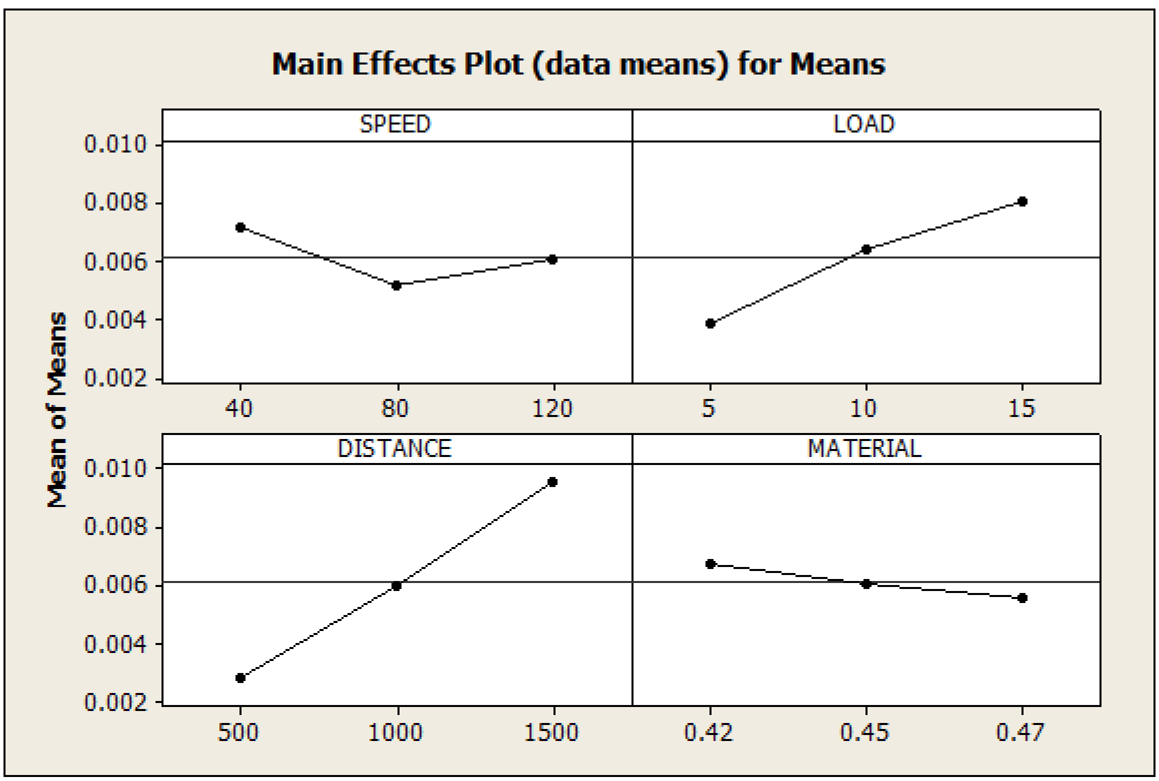


Fig. 2. Main effects plot for means- Weight loss

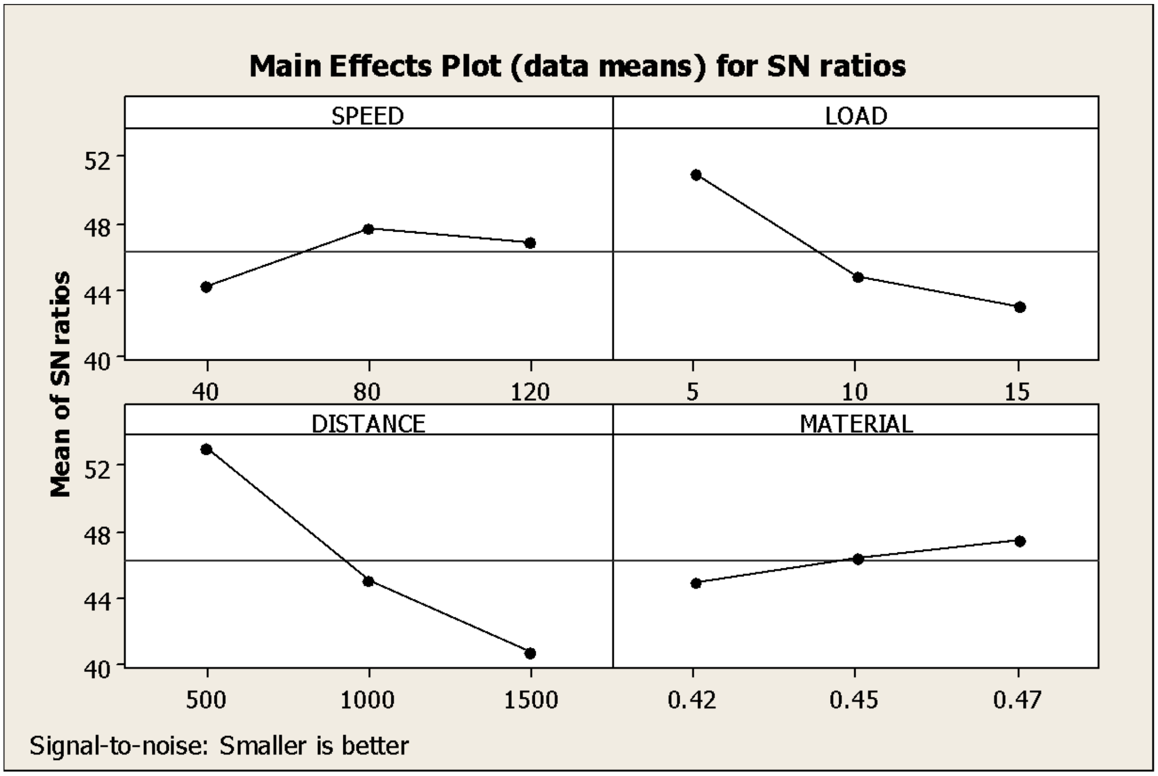


Fig. 3. Main effects plot for S/N Ratios-Weight loss

The model aims to reduce wear loss. S/N-ratio tests the exposure to non-controlled external influencing factors (noise factors) of the quality feature monitored in a standardized manner. The experiment attempts to determine S/N-ratio for the outcome (wear loss). It focuses on the type of character being evaluated, encapsulating multiple data points in a trial. It is possible to classify the Signal to Noise ratio features into 3 groups, viz. nominal is the best, larger the better & smaller the better. This study opted for the "smaller the better" feature to examine Cu-Al-Be SMA's dry-sliding wear behavior. S/N-ratio for 3 factors and 3 variables are calculated by smaller-is-better characteristics selected as we attempt to minimize wear loss.

Table 4: ANOVA for wear of Cu-Al-Be SMA

Factor	**Sum of squares**	**Degree of freedom**	**Variance**	**F – value**	**Test F**	**% of contribution**
Sliding distance	2.07	2	1.035	34.5	8.65^{a}	60.44
Load	0.84	2	0.42	14	8.65^{a}	24.26
Sliding speed	0.19	2	0.095	3.2	3.11^{c}	5.15
S*D	0.005	4	0.0125	0.83	-	0.59
S*L	0.09	4	0.0225	1.5	-	-

L*D	0.1	4	0.025	1.66	-	-
Error	0.06	8	0.0075			13.04
Total	3.4	26				100

Multiple Linear Regression Models

The MLR analysis attempts to model and connect at least two indicator and reaction factors by fitting a direct condition to the noticed information. To evaluate the relationship of wear parameters: sliding distance, applied load, sliding speed & material. Using the statistical program MINITAB R14, the dry sliding wear, weight loss, and wear obtained MLR models with statistically relevant terms included in the model. Model's regression coefficient given by

$$\mathrm{WEAR_{CABSMA}} = 0.00678 - (0.000013 \times \mathrm{S}) + (0.000418 \times \mathrm{L}) + (0.000007 \times \mathrm{D}) - (0.0236 \times \mathrm{M})$$

Where W=Weight loss, S=Sliding Speed, L=Applied Load, D=Sliding Distance, M =Material and R-Sq.= 98.5%

Conformation Experiment

In the software MINITAB-14, a confirmation test contrasts the analytical and practical findings. The comparison of wear results from the mathematical model compared with the various values obtained experimentally. The Multiple linear regression equation derived and correlated the evaluation of the selected material with a reasonable degree of approximation.

Table 5: Factors and Levels assignment for the conformation Experiment

Factor	Units	Level1	Level2	Level3
Sliding speed	rpm	50	75	100
Load	N	8	12	16
Sliding distance	M	600	900	1200
Material	wt%	CAB1	CAB2	CAB3

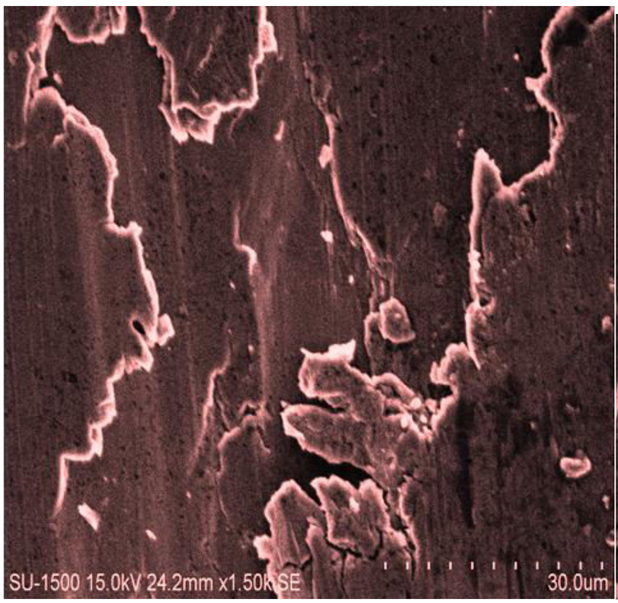
Table 6: The output of the conformation experiment and the Regression Model comparison

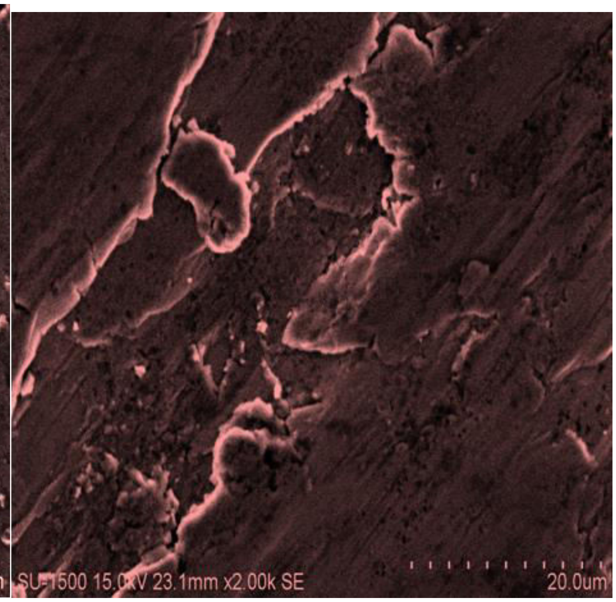
Exp. No.	Exp. weight loss (gm)	Regression model (7), weight loss (gm)	%Error
1	0.003892	0.003762	3.4
2	0.006578	0.006501	1.179

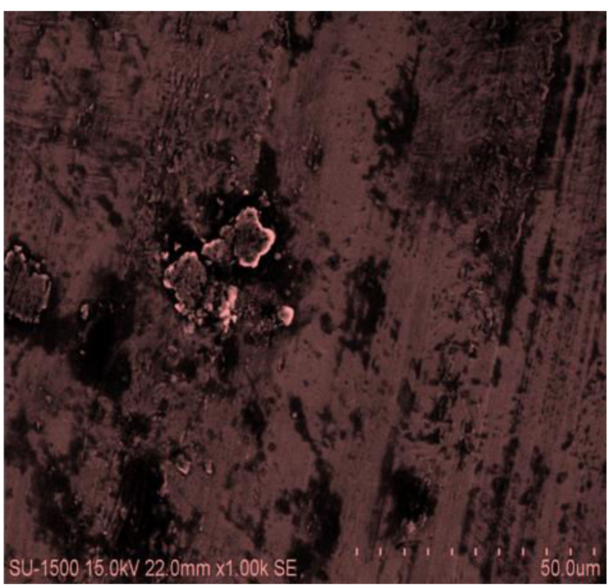
3	0.010134	0.009476	6.89

These qualities were intently taking after the real information with the least blunder; an investigation by the Taguchi approach found effective for computing weight reduction from the regression equation. From the research, Actual weight reduction is discovered to be fluctuating from the determined one utilizing the regression equation. For weight reduction, the blunder rate varies between 1.179 to 6.89 percent. These values exactly represent the real data with minimal error.

Morphology of worn surface







5. CONCLUSION

1. The Taguchi optimization technique was used to design the pin on the disc wear test using three specific parameters: Sliding Distance, Applied Load, and Sliding Speed.

2. Pin on disc wear test shows that the increase in sliding distance and applied load wear loss increases, but the wear loss decreases with the increase in sliding speed.

3. Signal shows the optimal outcome of under-considered parameters to Noise ratio graphs acquired from the "Taguchi Minitab14" Application.

4. ANOVA tests also verified that the three distinct parameters play a key role in wear.

5. The error from the confirmation test varies between 1.179 to 6.89 percent, leading to the inference that DOE was effective in using the Taguchi method for measuring erosion with the regression model.

6. Four main mechanisms, namely "abrasive," "adhesive," "brinelling wear," and "surface fatigue," are responsible for significant contributions to the wear characteristics of the studied SMA.

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