Optimization of tribological behaviour on Al- coconut shell ash composite at elevated temperature

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Abstract. In this study, determine the tribological behaviour of composite at elevated temperature i.e. 50 – 150 °C. The aluminium matrix composite (AMC) are prepared with compo casting route by volume of reinforcement of coconut shell ash (CSA) such as 5, 10 and 15%. Mechanical properties of composite has enhances with increasing volume of CSA. This study details to optimization of wear behaviour of composite at elevated temperatures. The influencing parameters such as temperature, sliding velocity and sliding distance are considered. The outcome response is wear rate (mm^3/m) and coefficient of friction. The experiments are designed based on Taguchi [L_9] array. All the experiments are considered as constant load of 10N. Analysis of variance (ANOVA) revealed that temperature is highest influencing factor followed by sliding velocity and sliding distance. Similarly, sliding velocity is most influencing factor followed by temperature and distance on coefficient of friction (COF). Finally, corroborates analytical and regression equation values by confirmation test.

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1. Introduction

In the current scenario, aluminium metal matrix composites (AMC) is preferred in most application due to lightness and cost effective.   Generally, AMCs are fabricated with matrix as aluminium (Al) and reinforcement is ceramics. AMCs has been attributed inherent strength, high strength modules, and better wear resistance with customize properties of thermal due to the addition of ceramics[1–4].

The reinforcements (ceramics) restricted the deformation of Al from load and distributed load uniformly throughout the base matrix with enhances the properties of composite. The preferred reinforcement is stated by several influencing factors would like to anticipated with application, kind of process, cost and availability. Many researchers are interested to use the natural minerals and agro-wastages as reinforcement owing to renewability, inexpensive, moderate recycled, and eco-friendly. However, various agro wastes like fly ash [5,6], red mud [7] and colliery shale[8,9] , rice husk [10], shell char [11–14], and bagasse [15] and jute [16] .

Moreover, still there is a sang in preparation of the composite in term of fabrication and processing of reinforcement [4]. Usually, AMC is fabricated by several ways i.e. liquid metallurgy (*i.e.,* stir or compo casting and infiltration), squeeze casting and powder metallurgy route. Generally, for the mass and low cast production, liquid metallurgy route is most preferred than the other ones.

Aku et al.[14]evaluated microstructure, hardness and density coconut shell ash composites having 3-15% weight volume. They found that by increasing the vol. % of reinforcement, density decreases and hardness values increases. Shen et al. [17] reported on the correlation between hardness and tensile strength of composite, based on the effect of particle size, volume fraction and aging behaviour of   prepared with Al-Cu-Mg alloy reinforced with SiC. Mahendra et al.[18] Prepared aluminium (2024) composites reinforced with SiC, fly ash and hybrid of SiC- fly ash at various volume fractions (0, 5, and 10%) by stir casting route. Moreover, the authors reported on mechanical properties i.e. density, tensile strength, hardness, % of elongation and yield strength of all the composites. Certainly, Hybrid composite is exhibit better mechanical properties than the other. Siva et al. [9] investigated the

mechanical properties, abrasion and frictional behaviour of Al-colliery shale (CS) and Al-Al$_2$O$_3$ composites under forged condition by using pin-on –disc set up. They reported that the mechanical properties like ductile, toughness, stiffness, tensile strength and percent of elongation exhibit better in Al-colliery shale than Al-Al$_2$O$_3$. The wear behaviour in the forged condition of Al-CS had superior characteristic than Al-Al$_2$O$_3$ and base matrix Aibodion and Hassan [19] studied the effect of mechanical and micro-structural properties on Al- Si-Fe reinforced with Silicon carbide of 5-25% of volume. The authors concluded that increase of reinforcement with increasing hardness, tensile strength, and porosity whereas decrease density and impact strength. The composite has improved mechanical properties due to the addition and uniform distribution of reinforcement (SiC) in the ductile matrix. Kok and Ozdin [20] investigated the wear mechanisms of the 2024 aluminium alloy composites reinforced with Al$_2$O$_3$. They reported that wear resistance of the composites was greater than the base alloy, and increased with "increasing reinforced particles size", also decreased with "increase of sliding distance, load and the abrasive particle size".

Similarly, few researchers made effort on elevated temperature which is a one of the main influencing factor in Tribology of composite materials. Rashed and Mahmoud [21] has developed A356-SiC composite by the way of rheo casting. The author reported on optimization of wear resistance of composite using artificial neural network (ANN) model. The contributed input parameters were size of SiC, volume fraction of SiC, applied pressure, and temperature. The wear resistance of base metal is inversely proportional characteristic to temperature. The composite exhibited better resistance up to 200 °C then significantly decreased. Gudlur et al.[22], reported on thermo mechanical properties of Al-Al2O3 composite. The properties of composite are estimated by numerical method and compared with OOF element code. Sharma et al. [23] investigated wear behaviour of AA7075-E glass fiber composite at elevated temperature up to 200 °C. They exposed composite exhibited better wear resistance than virgin due to delaying transitions wear. From the wear mechanism, severity in composite increased with increasing of applied load and temperature. Delaminated surfaces and debris are corroborating with by SEM-EDX.

Wilson and Alpas[24] prepared two aluminium (A356 and Al6061) composites with reinforcing volume of SiC (20%), Al$_2$O$_3$ (20%), and Gr (10%). They determined wear performance of developed composites at an elevated temperature up to 450 °C. The tested conditions was minimized to lower load (11.55 N), sliding speed (0.1m/s) in an isothermal atmosphere. The seizure condition of composites (i.e. A356-SiC and Al6061-Al$_2$O$_3$) is improved from 230 to 450 °C and 190 to 340 °C respectively as compared to base materials. The Gr addition deteriorates strength but enhances friability of composite.

This investigation is mainly intense towards preparation of aluminium based composite reinforced with agro waste i.e. coconut shell ash (CSA). The Al-CSA composite has been prepared by compo casting route with various percentage of CSA such as 5, 10, and 15% of volume. This study deals with investigation of mechanical properties, micro structural with wear resistance of composite at elevated temperature. The wear mechanism of composite has understood by SEM analysis.

2. Materials and Methods

2.1. Materials
In the present work, Al 1100 grade (Table 1) aluminium (HINDALCO, BBSR) is used as the matrix, whereas coconut shell ash is used as reinforcement for the preparation of composites.

Table 1 Chemical composition for Al-1100

Elements	Cu	Zn	Mn	Si	Fe	Al
%	0.05-0.2	0.1	0.05	0.7-0.95	0.35-0.85	Balance

2.2. Preparation of reinforcement and Composites

The list The Al-CSA composites are prepared using compo casting route. Initially, the collected coconut shells (CS) are dried and outer skins is smoothened then, crushed in a jaw crusher followed by a hammer mill in order to produce a coarser form of CS powder. The obtained powder is packed in a graphite crucible and fired in an electric resistance furnace at the temperature of 1320 °C and cooled at furnace temperature to form micro-sized coconut shell ash (CSA) powder. Finally, the CSA powder is sieved in a rotary sieve shaker with the size of ≤ 240 BSS mesh (63 microns). The obtained CSA is treated in tubular furnace under below (argon) atmospheric at a temperature of 1530 °C up to ≈4 hr. The final formed CSA particulate is used as reinforcement.

The compo casting technique has been employed for the preparation of AMCs. The aluminium matrix is pre-heated in a bottom pouring furnace at 450 °C and then raised melting temperature up to 670 °C to keep the matrix alloy in a semi-solid state. On the other hand, the CSA particles are pre-heated in a muffle furnace up to 3 hours for 1100 °C (CSA). Thereafter, the molten metal along with reinforcements is stirred with the help of a motor driven stirrer in the presence of argon gas at a speed of 600 rpm up to 9 minutes. Then, the molten metal is superheated above the liquid temperature at 690 °C and poured into a preheated (300 °C) cast iron mold of the size of $100 \times 20 \times 40$ mm^3.

2.3. Characterization techniques

The as-prepared AMCs were characterized for their structural, morphological and mechanical properties. X-ray diffraction pattern for CSA was recorded using an X-ray diffractometer (Phillips PW-1729) using CuKα radiation of wavelength λ = 0.1541 nm in the scan range 2θ = 10–60°. Morphology of the sample was investigated using scanning electron microscope (SEM with EDXA, JEOL JSM-5600LV). Microstructural examinations (ASTM E-7-95) of samples have been carried out using standard metallography technique (XJL-1000). The composite are performed with Brinell hardness tester with a load of 250 kg and 5 mm ball indenter. The tensile properties of the composites have been tested with Hounsfield tensometer (model: ETM-ER3/ 772/12) at a velocity of 1 mmsec^{-1} with a maximum load of 20 KN following the ASTM standard E8. Pin on the disc wear testing machine (Model: TR-201 LE-PHM 400) is used for conducting the wear test (ASTM-G99) experiments on composites.

2.4. Taguchi approach

Taguchi is a robust design to enhance the productivity during development of components at lower price. It reduces economically variation of productive functions to the customer environment[25,26]. In this study, Taguchi (L9) orthogonal array has been preferred to optimization of number of experiments. The specified input factors along with their levels are shown in Table 2. Moreover, output response is wear-rate (WR) and coefficient of friction (COF). To obtained outcomes, the experiments are designed with specified inputs such as Temperature, sliding distance and velocity. The designs of experiments are shown in Table 3. Furthermore, a statistical analysis of variance (ANOVA) has been performing to known input factor with significant. Ultimately, a corroboration regression equation is verifying the optimal process parameters.

Table 2. Used factors with their levels

S.No	Factors	Units	Levels		
			-1	0	1
1	Temperature (T)	°C	50	100	150
2	Sliding Distance (D)	m	1000	1500	2000
3	Sliding Velocity (V)	m/s	0.5	1	1.5

Table 3. Experimental design (L9)

Si.No	T	D	V
1	50	1000	0.5
2	50	1500	1
3	50	2000	1.5
4	100	1000	1
5	100	1500	1.5
6	100	2000	0.5
7	150	1000	1.5
8	150	1500	0.5
9	150	2000	1

Table 4. Chemical Composition of CSAp

Elements	Al2O3	CaO	Fe_2O_3	MgO	K_2O	MnO	Na_2O	SiO_2	ZnO
% of Wt.	21.42	2.67	4.42	18.2	0.59	0.25	0.47	48.2	0.32

3. Results and Discussion

3.1. Mechanical properties of Al-CSA composites

The coconut shell ash is subjected to analysis by XRD and details of chemical constitutes as shown in Table 4. Aluminium alloy (ISO 99.0Cu) has been used as the matrix in the present investigation. The density of receiving alloy was 2.71g/cc. Table 5 shows the variation of properties in AMCs. It is clear from the table that with an increase of % reinforcement the tensile strength is increased. The yield strengths are found to be 90, 101, 127, and 142 N/mm2 for pure, 5%, 10%, and 15% of volume in Al-CSA respectively. Similarly, the Hardness value is increased with increase in reinforcement as observed in Table 5, which is due to strain hardening of composite. Similarly, density and elongation decreases with increase of CSA volume in composite. Generally, reinforcement particles (CSAp) are harder, which increases load bearing capability, and restrict dislocation movement of the matrix reduces interspacing, particle movement has been critical.

3.2. Metallographic testing:

The microstructures of the pure and reinforced MMCs are presented as Fig. 1. The metallography images observed bright area specifies matrix and dark area specify reinforcement particles. The distribution of particles in the microstructure is seen to be uniform. It is also observed from Figure that with an increase in the % of reinforcement grain size decreases, which in turn increases the strength and decreases the ductility.

Table 5. Mechanical Properties of Al-CSA-MMCs

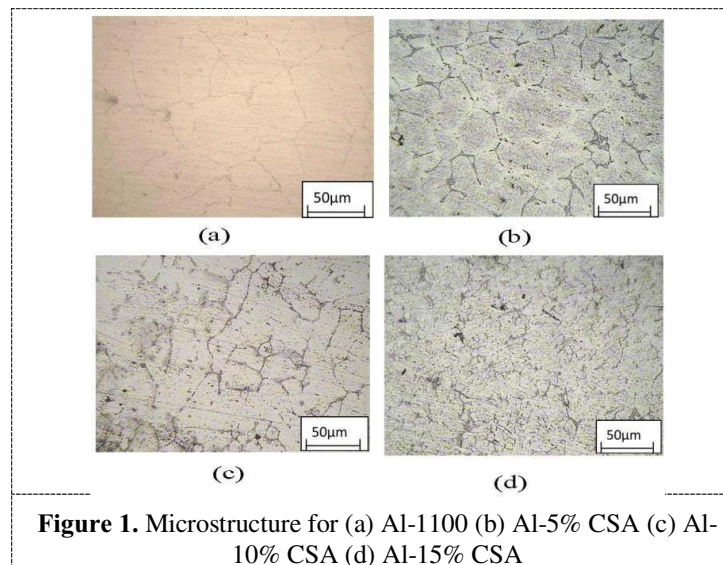| % of CSAp	0	5	10	15
VHN	56.3	61.1	78.4	82.1
Density(g/cc)	2.71	2.65	2.59	2.51
UTS(N/mm2)	90	101	127	142
% of Elog.(mm)	28	23	18	14

Figure 1. Microstructure for (a) Al-1100 (b) Al-5% CSA (c) Al-10% CSA (d) Al-15% CSA

Table 6. Outcome- response with S/N ratio

Run	WR(mm^3/m)	COF	WR SN ratio (dB)	COF SN ratio (dB)
1	0.002705	0.491	51.35665	6.182794
2	0.00207	0.488	53.68059	6.238726
3	0.001435	0.485	56.86296	6.295021
4	0.00232	0.554	52.69024	5.136078
5	0.001685	0.551	55.468	5.185642
6	0.002955	0.569	50.58885	4.901572
7	0.001935	0.616	54.26638	4.202043
8	0.003205	0.635	49.88344	3.947946
9	0.00257	0.632	51.80134	3.991158

3.3. S/N ratio results

The signal to noise ratio is attained by Taguchi technique. The ratio for each response has been resolute by averaging S/N ratios at the consequent level. The influencing factors such as Temperature, sliding distance, and sliding velocity on WR & COF for Al-CSA composites are detailed in Table 6. The influencing factors with the highest S/N ratio will give in the optimum feature with least variance can determine by the response Tables 7 and Table 8. The sliding velocity is a dominant factor on the wear rate, followed by temperature and sliding distance. Similarly, from Table 8 temperature is a main influencing factor followed by sliding velocity and distance for Coefficient of friction.

Table 7. Response table of wear rate

Level	Temp	SD	SV
1	53.97	52.77	50.61
2	52.92	53.01	52.72
3	51.98	53.08	55.53
Delta	1.98	0.31	4.92
Rank	2	3	1

Table 8. Response table of COF

Level	Temp	SD	SV
1	0.4876	0.5536	0.5647
2	0.5576	0.5576	0.5576
3	0.6276	0.5616	0.5504
Delta	0.14	0.008	0.0143
Rank	1	3	2

The main effect plot (Fig. 2) resulted that wear rate and coefficient of friction are increased with increase of temperature and sliding distance and decreased with sliding velocity.   The optimum input factors are temperature (50 ° C), sliding distance (1000 m), and sliding velocity (0.5 m/s) irrespective of the wear rate and coefficient of friction.
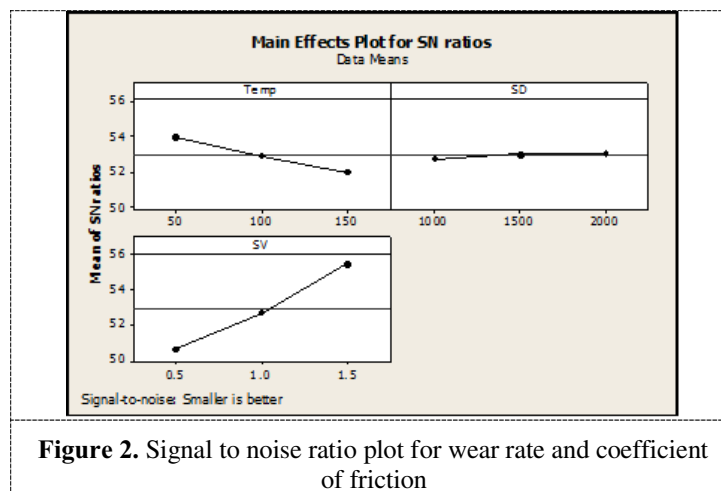
Figure 2. Signal to noise ratio plot for wear rate and coefficient of friction

3.4. Analysis of variance (ANOVA)
ANOVA is a technique of portioning changeability into certain source of disparity and the related degree of freedom in experimentation. The frequency test (F-test) is exploiting in statistics to examine the important effect of input factor, which form the quality characteristics. Table 9&10 shows the result of linear effect on ANOVA analysis of S/N ratio of wear rate (WR) and coefficient of friction (COF). This analysis was carried out for a level of significance of 5%, i.e., for 95% a level of confidence. The last column of the table shows the "percent contribution" (P) of each factor as the total variation, indicating its influence on the result.

Table 9. ANOVA of wear rate

Source	DF	Seq SS	Adj SS	Adj MS	F	P
T	2	5.9056	5.9056	2.9528	35.99	0.027
D	2	0.161	0.161	0.0805	0.98	0.505
V	2	36.5917	36.5917	18.2959	223.01	0.004
Error	2	0.1641	0.1641	0.082		
Total	8	42.8224				
S = 0.2864		R-Sq = 99.6%		R-Sq(adj) = 98.5%		

Table 10. ANOVA of COF

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Temp	2	7.21536	7.21536	3.60768	32096.5	0.001
SD	2	0.01857	0.01857	0.00929	82.61	0.012
SV	2	0.07052	0.07052	0.03526	313.69	0.003
Error	2	0.00022	0.00022	0.00011		
Total	8	7.30467				
S = 0.01060		R-Sq = 97.5%			R-Sq(adj) =96.4%	

4. Multiple linear regression and Confirmation test

Multiple linear regression equations were developed to establish the association amid of input factors and outcome. The value of regression coefficient R^2 (0.996 & 0.975) is in good agreement with the adjusted R^2 (0.985 & 0.964) for the wear rate and coefficient of friction respectively. In view of both values are logically close to unity, the models provide a good justification for the liaison among input factors and outcome response.

The regression equation developed for the wear rate of Al-CSA composite is as follows:

SRN WR = 0.000935 -0.000143 Temp + 0.000131 SD + 0.000228 SV – (1)

The regression equation developed for the coefficient of friction of the Al- CSA composite is as follows:

SRN COF = 0.313 + 0.0715 Temp + 0.00954 SD + 0.0325 SV – (2)

From the observation of Equations (1) & (2) that the temperature   (T) plays a major role on wear rate, followed by sliding velocity (V) and sliding distance (D). The coefficient associated with temperature (T) is negative, thus indicating that the wear rate and coefficient of friction decreases with increasing temperature. Conversely, the wear rate increases with increasing sliding distance and sliding velocity because the coefficients allied with these factors are positive. Sliding velocity is a larger effect on wear rate and coefficient of friction compared with the sliding distance according to its coefficient value.

Assessment of confirmation has been performing to corroborate the numerical analysis by choice trial conditions that are dissimilar from those employed in the analysis. The factors utilized in the confirmation test are offered in Table 11.

Table 11. Parameters used in the confirmation test

TEST	T	D	V
1	50	1500	1.5
2	100	1000	0.5

Tentative outcome are evaluate with the estimated values developing from the regression equation. Table 12 shows that the experimental values and calculated values from the regression equation are nearly the same with the least error (±5%). The resulting equations are capable of predicting the surface roughness to an acceptable level of accuracy.

Table 12 Results of confirmation test.

	Test 1			Test 2		
	Model Eq.	Exper.	%Error	Model Eq.	Experi.	%Error
WR	0.00145	0.00132	2.153	0.00274	0.00282	-4.953
COF	0.482	0.481	1.11	0.551	0.554	-3.619

5. Conclusions

- The Al-CSA composites are prepared with compo casting route by various percentage of volume 5, 10, and 15.
- Mechanical properties of composites such as tensile strength and hardness have been increased. Similarly, elongation and density decreased with increasing volume of CSA in Al composite.
- Morphological examination revealed that grain size decreasing with increase of reinforcement, which enhance the hardness of composite.
- Temperature has the highest influence on wear rate and coefficient of friction in the wear behaviour of Al- CSAp composite followed by sliding velocity and sliding distance.
- Optimal wear behavioral conditions, such as temperature (50 °C), sliding velocity (0.5 m/s), and distance (1000 m), can be used to achieve the minimum wear rate and coefficient of friction, Al-CSAp composites.

6. References

[1]   Adams D F 1987 *Composites* **18** 261
[2]   Miracle D B 2005 *Compos. Sci. Technol.* **65** 2526–40
[3]   Rohatgi P K 1993 *Def. Sci. J.* **43** 323–49
[4]   Surappa M K 2003 *Sadhana* **28** 319–34
[5]   Govindarao R, Ganguly R I, Dash R R, Surya Prakash Rao P, Reddy G S and Singh S K 2015 *Trans. Indian Inst. Met.* **68** 951–8
[6]   Rohatgi P K, Daoud A, Schultz B F and Puri T 2009 *Compos. Part A* **40** 883–96
[7]   Prasad N, Sutar H, Mishra S C, Sahoo S K and Acharya S K 2013 *Int. Res. J. Pure Appl. Chem.* **3** 59–74
[8]   Venkata Siva S B, Ganguly R I, Srinivasa Rao G and Sahoo K L 2015 *J. Eng. Tribol.* **229** 823–34
[9]   Venkata Siva S B, Ganguly R I, Srinivasa Rao G and Sahoo K L 2014 *Tribol. - Mater. Surfaces Interfaces* **8** 117–24
[10]   Alaneme K K, Akintunde I B, Olubambi P A and Adewale T M 2013 *J. Mater. Res. Technol.* **2** 60–7
[11]   Siva Sankara Raju R, Panigrahi M K, Ganguly R I and Srinivasa Rao G 2016 *31st indian engineering congress,kolkata* ed I Nilanjan senpupta (Kolkata: Allied publishers pvt. Ltd) pp 241–5
[12]   Siva Sankar Raju R, Srinivasa Rao G and Muralidhara rao M 2015 *Int. J. Conceptions Mech. Civ. Eng.* **3** 17–21
[13]   Murali T P, Surappa M K and Rohatgi P K 1982 *Metall. Trans. B* **13** 485–94
[14]   Aku S Y, Yawas D S and Apasi A 2013 *Gazi Univ. J. Sci.* **26** 449–57
[15]   Aigbodion V S, Hassan S B, Dauda E T and Mohammed R A 2011 *Tribol. Ind.* **33** 28–35
[16]   Biswas B, Chabri S, Mitra B C, Bandyopadhyay N R and Sinha A 2016 *J. Inst. Eng. Ser. C* 1–6
[17]   Shen Y L, Williams J J, Piotrowski G, Chawla N and Guo Y L 2001 study *Acta Mater.* **49** 3219–29
[18]   Boopathi M, Arulshri K P and Iyandurai N 2013 *Am. J. Appl. Sci.* **10** 219–29
[19]   Aigbodion V S and Hassan S B 2007 *Mater. Sci. Eng. A* **447** 355–60
[20]   Kök M and Özdin K 2007 *J. Mater. Process. Technol.* **183** 301–9
[21]   Rashed F S and Mahmoud T S 2009 *Tribol. Int.* **42** 642–8
[22]   Gudlur P, Muliana A and Radovic M 2014 *Compos. Part B Eng.* **58** 534–43
[23]   Sharma S C, Krishna M, Vizhian P S and Shashishankar A 2002 *Proc. Inst. Mech. Eng. Part D J. Automob. Eng.* **216** 975–82
[24]   Wilson S and Alpas A T *Wear* 1996 **196** 270–8
[25]   Taguchi G 1986 *Vol. 4* (Tokyo: Asian Productivity Organization.) p 191

[26]   Phadke M S 1989 *Vol. 1* (AT & T Bell Laboratories,Holmdel ,New Jersey: P T R Prentice Hall, Englewood Cliffs,New Jersey 07632) pp 1–327