ANALYSIS OF DRY SLIDING WEAR BEHAVIOUR OF AL 6061- COCONUT SHELL ASH METAL MATRIX COMPOSITES USING STIR CASTING

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Abstract:
Al6061 with hard particle reinforcement contains higher stiffness, maximum strength and wear resistance when compare to unreinforced alloy. They can be usage for self-propelled automotive components and aircraft construction. Metal matrix composite (MMC) concentrate chiefly on amended specific strength and wear resistance application. Aluminium as base material and coconut shell ash(CSA) as reinforcement has good potential. The principle difficult is to create this composite in a practical manner. In this project Al6061-CSAp castings with different volume fraction of CSA were produced in an argon atmosphere by an enhanced stir casting method. We found that with more % of CSA addition there is an improvement in specific strength of the composite. Pin on disc equipment used for dry sliding wear analysis of MMCs. The Taguchi analysis revealed the improved specific strength as well as wear resistance. EDS analyses showed oxide phases presence in the castings. Surface Morphology particle distribution were examined in detail by SEM.

1. INTRODUCTION

A Composite material can be formed by combining two or more dissimilar materials together. The mechanical properties of the composites will be better than the individual components. The composite materials will be composed of two or more phases. They are matrix phase and reinforcement phase [1].

The metal is the major part and the minor constituents are reinforcements may be in the form of particles, whiskers, continuous and discontinuous fibres. The reinforcement material may be a ceramic or organic in nature. MMC consists of superior mechanical, physical and electrical properties. Hybrid composite consists of more than two constituting materials [4]. Aluminium Matrix Composites are extensively used due to their desirable superior properties. The applications are diversified in production, thermal, marine and automobile industries like marine, aircrafts, automobiles, electrical wires and household utensils. T.Nithyanandhan, K.Rohith, C.G Sidharath, C.Sachin, Sarayu Jagadesh investigated the mechanical behaviour of Aluminium metal matrix hybrid composite containing B_4C & coconut shell ash as reinforcement at various percentage. The hardness, tensile strength is decreases slightly than base metal [2]. P.B Madakson, D.S.Yawas and A. Apasi, was made an attempt to investigate the characteristics of coconut shell ash. The microscopic analysis reveals that element like SiO_2, Al_2O_3, MgO and Fe_2O_3 as major constituents and hard in nature leads to its utilization in automobile applications. As coconut shell ash has high thermal stability with low density, can be used in producing composite products with good thermal resistance. [6-8].

P. Lakshmi Kanthan, Dr. B. Prabu, focused on synthesis and determination of mechanical and tribological properties of aluminium alloy Al6061-Coconut Shell Ash (CSA). It is observed that 6% CSA reinforced composite has the maximum tensile strength, maximum hardness and minimum wear [9].

The current state, demands towards development of engineering material to various specific problems in an exertion to overcome the challenge in manufacturing via tools and materials. Metal Matrix Composites (MMCs) bring significant profit due to attainable properties are prominent for the components concerned [10]. The number of metallic alloys employed industrially is very high and new composition is being tested for employed to meet new diversify demands of many industries. Moreover, the innumerable alloys, aluminium alloy find the wide application in industrial and technology due to as high strength – weight ratio, specific modulus, and high wear resistance. Precisely, Aluminium Metal Matrix Composites (AMC) are effectively implemented in few industrial applications like aerospace, automotive, defence, and electronic packing [12,13].

2. SELECTION OF MATERIALS

2.1 Preparation of Coconut Shell Ash

Coconut shells is collected and dried in sun for 7 days. The burned out is crushed in a jaw crusher and ball mill respectively to get fine particles [3]. The powder is exposed to an argon gas at 1150°C for 3 hours. The ash is further grinded in a ball mill and is screened to a fine size of 200 mesh (≈45 μm) to use as reinforced particles. The chemical composition of Al6061 alloy and CSA presented in Table 1 and Table 2 respectively.

Table 1. Chemical Composition of Al 6061

Element	Mg	Si	Fe	Cu
Weight %	1.08	0.63	0.17	0.32
Cr	Zn	Mn	Others	Al
0.014	0.25	0.52	0.05	remaining

Table 2. Chemical Composition of CSA

Element	Al_2O_3	Fe_2O_3	CaO	K_2O
Weight %	15.6	12.4	0.57	0.52
MgO	Na_2O	MnO	Si_2O	Al
16.2	0.45	0.22	45.05	0.3

3. EXPRIMENTAL WORK

3.1 Methodology

Al6061 alloy of 1.5 kg was placed in stir casting machine to heat up to 750^{0}C, along with 1.0 wt. % preheated flux, and wt.% reinforcement at 300^{0}C in an oven. Argon gas envirnment is provided to avoid oxidation. Preheated flux was added to the melt and allowed for homogenization for 5–6 min by agitating of stirrer in the melt. After removal of slag from the surface, preheated (up to 300^{0}C) CSA particles were added into the vortex of the melt during stirring.[5] The mixture is allowed to stir at 600 rpm for 10 min. The melt is allowed into a two finger die of 270mm length and 22mm diameter while stirring. The same process is repeated for reinforcement 3% and 5%. The ingots with and without reinforcement composites are subjected to a heat treatment for 24 hrs at 110^{0}C in muffle furnace for homogenation. Compositions of Composites shown in Table 3.

Table 3. Compositions of Composites

Specimen. No	Composition	Al6061 Wt%	CSA Wt%
C1	Al 6061	100	0
C2	Al 6061 + CSA (1%)	99	1
C3	Al 6061 + CSA (2%)	98	2
C4	Al 6061 + CSA (3%)	97	3
C5	Al 6061 + CSA (4%)	96	4
C6	Al 6061 + CSA (5%)	95	5
C7	Al 6061 + CSA (6%)	94	6

4. RESULTS AND DISCUSSION

4.1 Density

The particle density of CSA determined was 2.05 g/cm^3 while the density of the Al6061 alloy was 2.67 g/cm^3. Since CSA has lower density than Al6061 alloy, its addition to the composite will make the density of the composite to be less than that of the alloy [11]. The density of composite at various proportions is discussed in Table 4 which are decreased with increase in percentage of reinforcement. Comparisiton of densities are shown in Fig.1.

Table 4. Comparison of Densities

S. No	Composition	Theoretical Density (g/cc)	Experimental Desnity (g/cc)
1	C1	2.700	2.700
2	C2	2.690	2.640
3	C3	2.686	2.620
4	C4	2.680	2.610
5	C5	2.674	2.590
6	C6	2.667	2.580
7	C7	2.661	2.570

Fig.1 Comparision of Densities

4.2 Porosity Measurement

The Porosity of the metal matrix composites presented in Table 5.

Table 5. Porosity Measurement

S. No	Sample	The Density (g/cc)	Meas Density (g/cc)	%Porosity = ((The-Meas)/The) *100
1	C1	2.700	2.700	0.00
2	C2	2.690	2.640	1.86
3	C3	2.686	2.620	2.46
4	C4	2.680	2.610	2.61
5	C5	2.674	2.590	3.14
6	C6	2.667	2.580	2.51
7	C6	2.661	2.570	2.61

4.3 Micro Vickers Hardness

The hardness of the composite is determined by using Vickers micro harness tester [14]. The micro hardness of composites is increases for C_1 to C_7 as shown in Fig.2. The increase in hardness is due to the present of hard particles in the reinforcement.
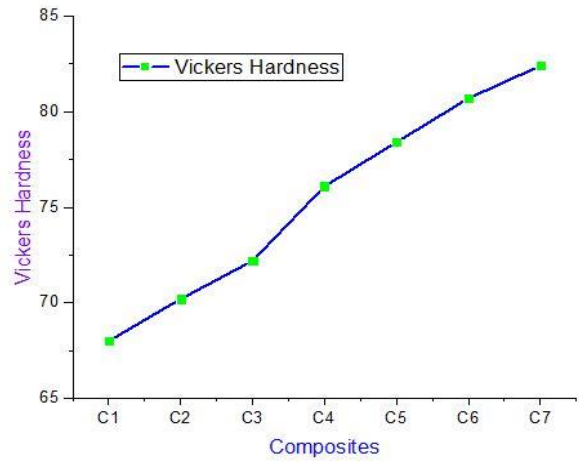

Fig.2 Variation of Vickers Hardness Number

4.4. Tensile behaviour of Al 6061 with CSA

Tensile strength of the composite is determined with ASTM E8 (Fig.3) specimen using universal testing machine. Tensile strength of the composite from C_1 to C_7 is as shown in Fig.4. The strength of the composite is found to be increasing with an increase in addition of reinforcement [15]. The maximum tensile stress obtained was 143.66 MPa for C_7 composites.
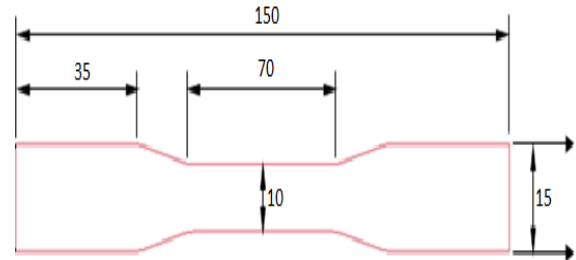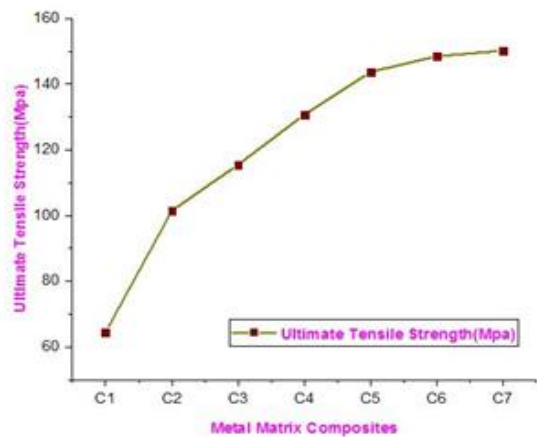

Fig.3. ASTM E8 Specimen

Fig.4. Variation of Ultimate Tensile Stress(Mpa)

4.5 Wear Analysis (Taguchi method)

The wear behaviour of the composite is determined by using Pin on Disc wear tester with the ASTM G99 standard specimen. The objective of the experimental plan is to calculate the important factors and combination of factors affecting the wear process to achieve the minimum wear rate and coefficient of friction. The experiments were performed on an orthogonal array, with the objective of the effect of sliding speed, applied load and sliding distance. The specified input parameters along with their levels are shown in Table 6. The designs of experiments are shown in Table (7,8,11,14) shows the experimental results average of two repetitions for wear rate and coefficient of friction. The ranking of process parameters using signal to noise ratios obtained for different parameter levels for wear rate and coefficient of friction are given in Table (9,12,15) and Table (10,13,16) respectively for 1%,3% & 5% reinforced CSA MMCs.

Table 6. Process Parameters and levels

Level	Load (N)	Sliding Speed,S (m/s)	Sliding Distance,D (m)
1	15	0.5	500
2	25	1.0	750
3	35	1.5	1000

Table 7. Orthogonal array L9 of Taguchi

Exp No.	Column 1	Column 2	Column 3
1	15	0.5	500
2	15	1.0	750
3	15	1.5	1000
4	25	0.5	500
5	25	1.0	750
6	25	1.5	1000
7	35	0.5	500
8	35	1.0	750
9	35	1.5	1000

Table 8. Results of L9 Orthogonal array for Al – 6061 / 1% CSA

S No.	L (N)	S (m/s)	D (m)	COF	Wear rate (mm^3/m)	S/N ratio c.o.f	S/N ratio wear rate
1	15	0.5	500	0.4867	0.0043	6.255	47.33
2	15	1.0	750	0.3533	0.0062	9.036	44.15
3	15	1.5	1000	0.3267	0.0076	9.717	42.38
4	25	0.5	500	0.3720	0.0095	8.589	40.45
5	25	1.0	750	0.3480	0.00101	9.168	59.91
6	25	1.5	1000	0.3200	0.00148	9.897	56.59
7	35	0.5	500	0.3371	0.0082	9.443	41.72
8	35	1.0	750	0.2971	0.00114	10.54	58.86
9	35	1.5	1000	0.2600	0.00168	11.70	55.49

Table 9. Responses table for S/N ratio for wear (1%CSA)

Level	Load	Sliding Velocity	Distance
1	44.62	43.17	54.26
2	52.32	54.31	46.70
3	52.03	51.49	48.01
Delta	7.70	11.14	7.57
Rank	2	1	3

Table 10. Responses table for S/N ratio for coefficient of friction (1% CSA)

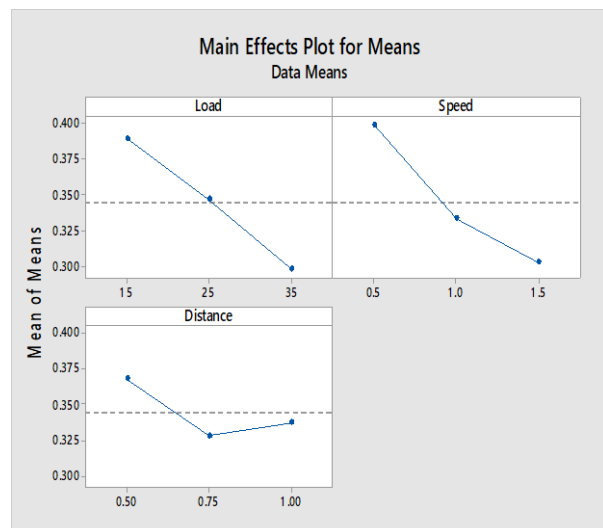| Level	Load	Sliding Velocity	Distance
1	8.337	8.096	8.898
2	9.218	9.582	9.775
3	10.562	10.438	9.443
Delta	2.225	2.342	0.878
Rank	2	1	3

Fig.5. Main effects for plot for Means –Coefficient of Friction(1% CSA)
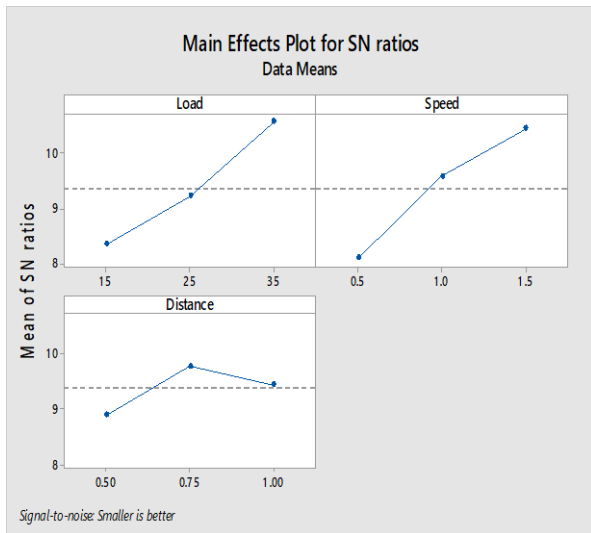
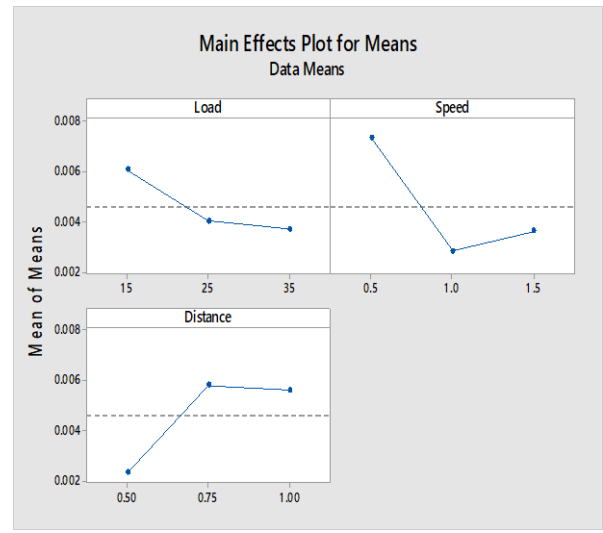**Fig.6.** Main effects for plot for S/N Ratios – Coefficient of Friction (1% CSA)

Fig.7. Main effects for plot for Means –Wear Rate (1%CSA)

Table 11. Results of L9 Orthogonal array for Al – 6061 / 3% CSA

S No	L (N)	S (m/s)	D (m)	COF	Wear rate (mm^3/m)	S/N ratio c.o.f	S/N ratio wear rate
1	15	0.5	500	0.4467	0.0040	7.000	47.958
2	15	1.0	750	0.3667	0.0055	8.714	45.192
3	15	1.5	1000	0.3867	0.0050	8.253	46.020
4	25	0.5	500	0.3680	0.0041	8.683	47.744
5	25	1.0	750	0.3440	0.0087	9.268	41.209
6	25	1.5	1000	0.3400	0.00138	9.370	57.202
7	35	0.5	500	0.2314	0.0056	12.711	45.036
8	35	1.0	750	0.0857	0.00123	21.338	58.201
9	35	1.5	1000	0.3743	0.00115	8.5359	58.786
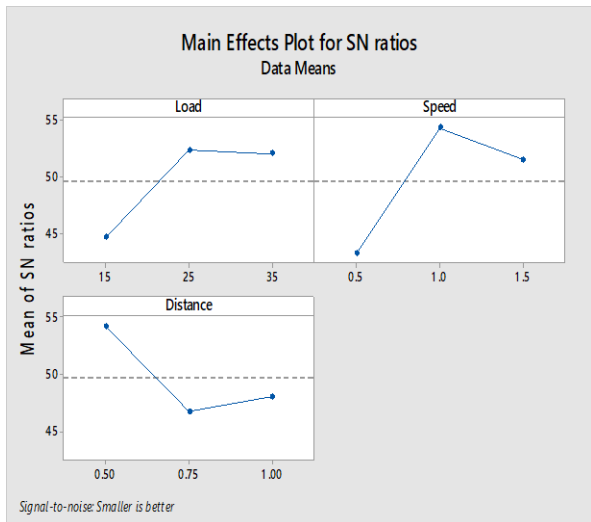
Fig.8. Main effects for plot for S/N Ratio –Wear Rate (1%CSA)

Fig.5-8 shows Main effects for Means and S/N ratio plots for 1% influence of process parameters on wear rate and coefficient of friction graphically.

Table 12. Responses table for S/N ratio for wear (3% CSA)

Level	Load	Sliding Velocity	Distance
1	46.39	46.91	54.45
2	48.72	48.20	50.57
3	54.01	54.00	44.09
Delta	7.62	7.09	10.37
Rank	2	3	1

Table 13. Responses table for S/N ratio for coefficient of friction (3% CSA)

Level	Load	Sliding Velocity	Distance
1	7.989	9.465	12.570
2	9.107	13.107	8.645
3	14.196	8.720	10.078
Delta	6.206	4.388	3.925
Rank	1	2	3

Fig.9-12 shows Main effects for Means and S/N ratio plots for 3% influence of process parameters on wear rate and coefficient of friction graphically.
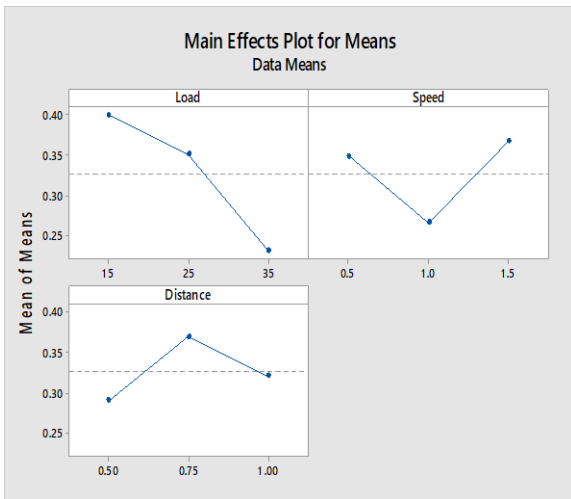
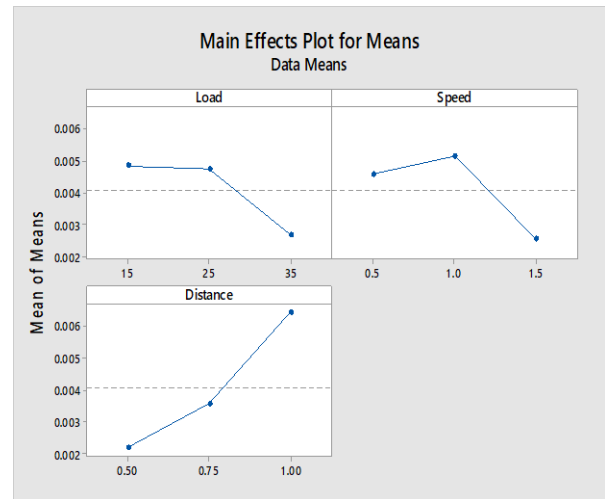**Fig.9.** Main effects for plot for Means –Coefficient of Friction(3% CSA)

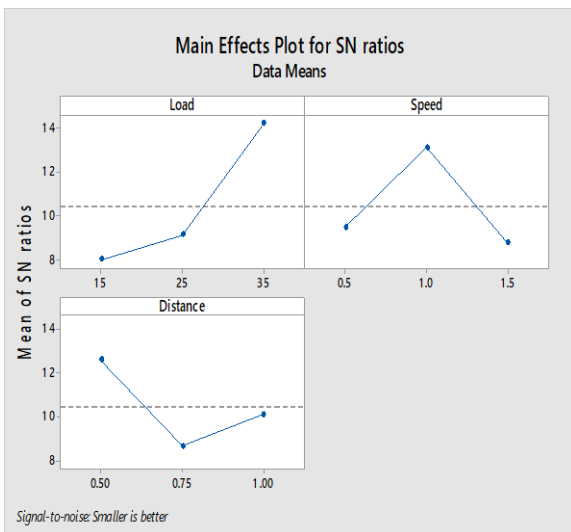**Fig.11.** Main effects for plot for Means – Wear Rate (3% CSA)

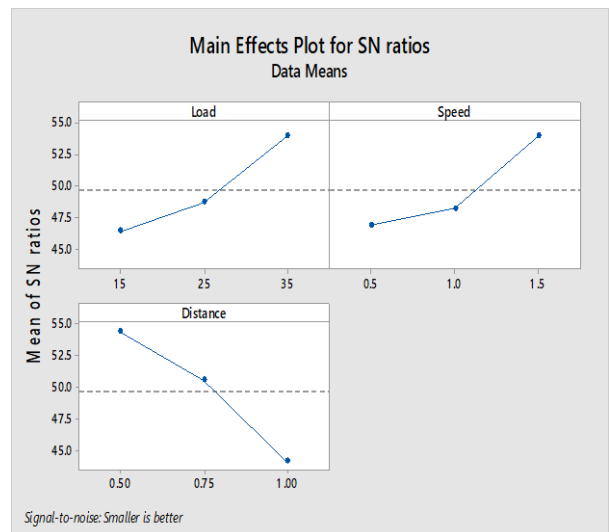**Fig.10.** Main effects for plot for S/N Ratios –Coefficient of Friction (3% CSA)

Fig.12. Main effects for plot for S/N Ratio – Wear Rate(3% CSA)

Table 14. Results of L9 Orthogonal array for Al – 6061 / 5% CSA

S No.	L (N)	S (m/s)	D (m)	COF	Wear rate (mm³/m)	S/N ratio c.o.f	S/N ratio wear rate
1	15	0.5	500	0.4733	0.0051	6.4967	45.8486
2	15	1.0	750	0.3667	0.0083	8.7146	41.6184
3	15	1.5	1000	0.3600	0.0093	8.8739	40.6303
4	25	0.5	500	0.3240	0.0033	9.7891	49.6297
5	25	1.0	750	0.3920	0.0095	8.1343	40.4455
6	25	1.5	1000	0.3480	0.0068	9.1684	43.3498
7	35	0.5	500	0.4429	0.0043	7.0747	47.3306
8	35	1.0	750	0.1486	0.0015	16.561	56.4782
9	35	1.5	1000	0.2829	0.0067	10.968	43.4785

Table 15. Responses table for S/N ratio for wear(5%CSA)

Level	Load	Sliding Velocity	Distance
1	42.70	47.60	48.56
2	44.48	46.18	44.91
3	49.10	42.49	42.80
Delta	6.40	5.12	5.76
Rank	1	3	2

Table 16. Responses table for S/N ratio for coefficient of friction (5% CSA)

Level	Load	Sliding Velocity	Distance
1	8.028	7.787	10.742
2	9.031	11.137	9.824
3	11.535	9.670	8.028
Delta	3.506	3.350	2.714
Rank	1	2	3

Fig.13-16 shows Main effects for Means and S/N ratio plots for 5% influence of process parameters on wear rate and coefficient of friction graphically.
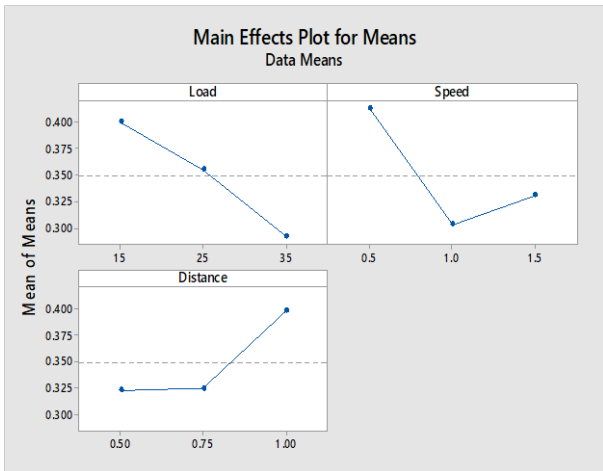

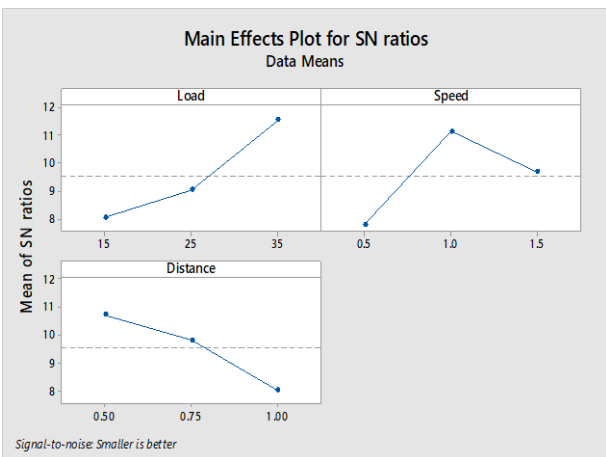**Fig.13.** Main effects for plot for Means – Wear Rate (5% CSA)

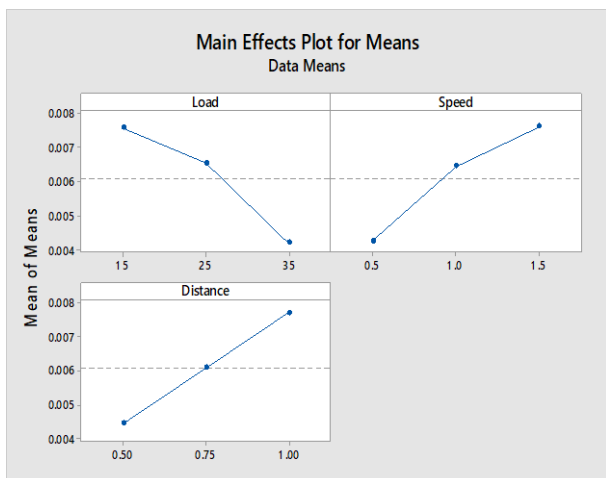**Fig.14.** Main effects for plot for S/N Ratios –Coefficient of Friction(5% CSA)

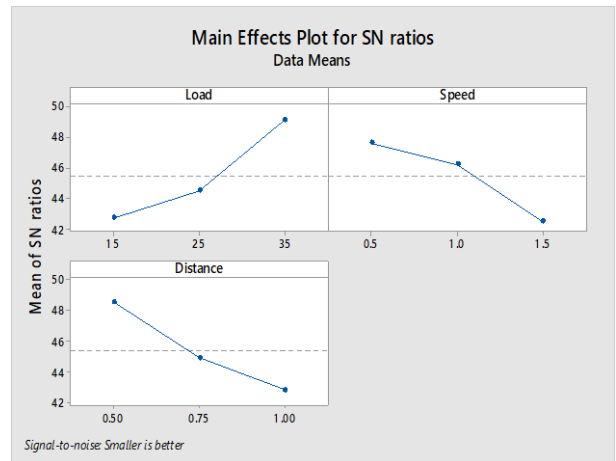**Fig.15.** Main effects for plot for Means –Wear Rate(5% CSA)

Fig.16. Main effects for plot for S/N Ratios –Coefficient of Friction

4.6 Analysis of variance (ANOVA)

ANOVA is a method of portioning changeability into some source of disparity and the related degree of freedom in experimentation. This analysis was carried out for a level of significance of 5%, i.e., for 95% a level of confidence. Table (17,18), Table (19,20) and Table (21,22) shows 1%,3% & 5% respectively CSA MMCs of the ANOVA results for wear rate and coefficient of friction for three factors varied at three levels and interactions of those factors.

It can be observed that for CSA (1%,3% & 5%) Composites, from the Table 17 and 22, that the sliding distance has the highest influence on wear rate.

Hence sliding distance is an important control factor to be taken into consideration during wear process followed by applied loads respectively.

From the analysis of variance & S/N ratio, it is inferred that the sliding distance has the highest contribution on wear rate & coefficient of friction followed by load & sliding speed.

Table 17. Analysis of Variance for Means (Wear Rate) (1% CSA)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Load	2	0.000010	0.000010	0.000005	0.42	0.705
Speed	2	0.000035	0.000035	0.000018	1.51	0.399
Distance	2	0.000023	0.000023	0.000012	0.98	0.504
Residual Error	2	0.000023	0.000023	0.000012		
Total	8	0.000092				

Table 18. Analysis of Variance for Means (Coefficient of Friction) (1% CSA)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Load	2	0.012385	0.012385	0.006193	6.53	0.133
Speed	2	0.014553	0.014553	0.007276	7.67	0.115
Distance	2	0.002578	0.002578	0.001289	1.36	0.424
Residual Error	2	0.001897	0.001897	0.000949		
Total	8	0.031413				

Table 19. Analysis of Variance for Means (Wear Rate) (3% CSA)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Load	2	0.000009	0.000009	0.000005	4.29	0.189
Speed	2	0.000011	0.000011	0.000006	5.48	0.154
Distance	2	0.000028	0.000028	0.000014	13.30	0.070
Residual Error	2	0.000002	0.000002	0.000001		
Total	8	0.000051				

Table 20. Analysis of Variance for Means (Coefficient of Friction) (3% CSA)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Load	2	0.045618	0.045618	0.022809	2.47	0.288
Speed	2	0.017570	0.017570	0.008785	0.95	0.513
Distance	2	0.009509	0.009509	0.004755	0.51	0.660
Residual Error	2	0.018484	0.018484	0.009242		
Total	8	0.091181				

Table 21. Analysis of Variance for Means (Wear Rate) (5% CSA)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Load	2	0.000018	0.000018	0.000009	1.96	0.337
Speed	2	0.000018	0.000018	0.000009	1.89	0.346
Distance	2	0.000016	0.000016	0.000008	1.69	0.372
Residual Error	2	0.000009	0.000009	0.000005		
Total	8	0.000061				

Table 22. Analysis of Variance for Means (Coefficient of Friction) (5% CSA)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Load	2	0.0178	0.0178	0.00892	0.78	0.561
Speed	2	0.0200	0.0200	0.01000	0.88	0.533
Distance	2	0.0110	0.0110	0.00553	0.49	0.673
Residual Error	2	0.0228	0.0228	0.01140		
Total	8	0.0717				

5. SEM AND EDS INVESTIGATIONS

Fig.17-20 illustrates SEM images of the metal matrix composites. As shown in (Fig.17), the 0 wt. % of coconut shell ash display a fractured area, indicating smooth surface but in the 1 wt. % coconut shell ash composite, there are toughening mechanisms cause of CSA particle like deboning and crack deflection. It can be seen these mechanisms in (Fig.18). In addition to this, fracture surface of 3wt.% (Fig.19) coconut shell ash composite has large plastic deformation areas. So, it can be easily understand that why adding coconut shell ash to improve the strength and strain of composite materials. The 5 wt.% of CSA shown in in Fig.20.

SEM and EDS for the composites are considered for microscopic analysis, at the interface (Fig.21-24) shows the presence of elements such as C, Mg, Al, Si, Ca, and Fe. Grain sizes decreases, due to pinning effect at the grain boundary. Fine grain size of composite contributes to strength by Orowan Mechanism. Average sizes of grains measured for composites from C_1 to C_4 are 46, 35, 28 and 16 μm.
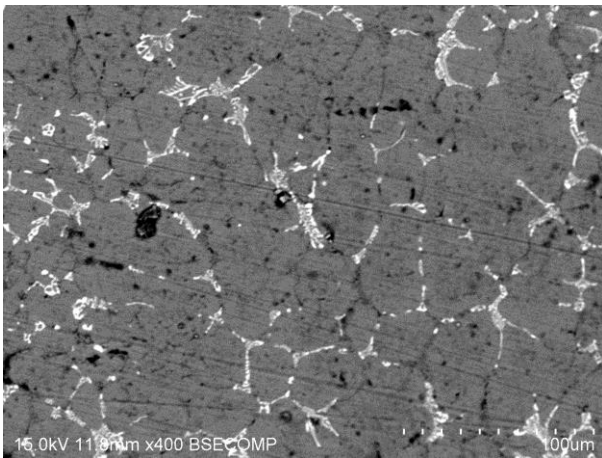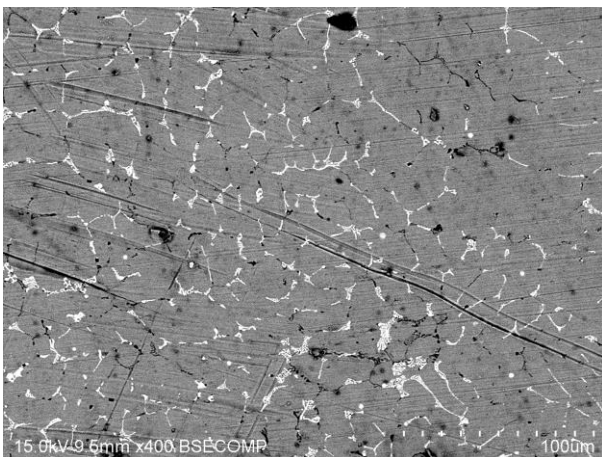

Fig. 17. The SEM of Al 6061

Fig.18. The SEM of 1% CSA
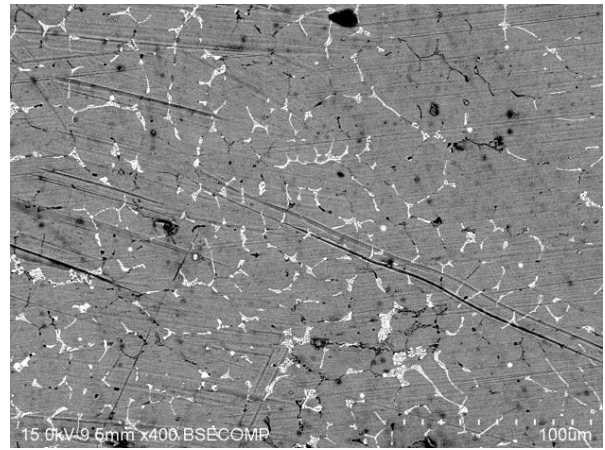

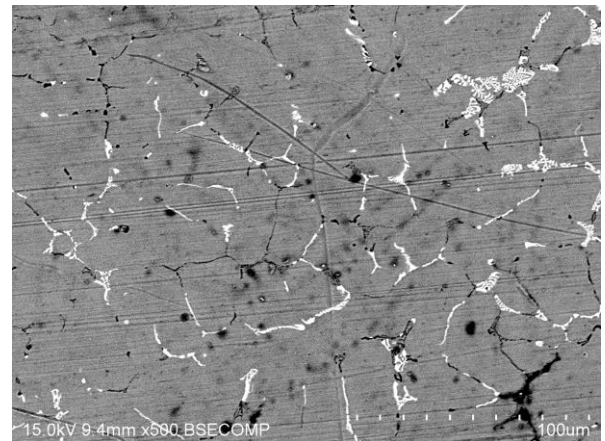**Fig.19.** The SEM of 3% CSA

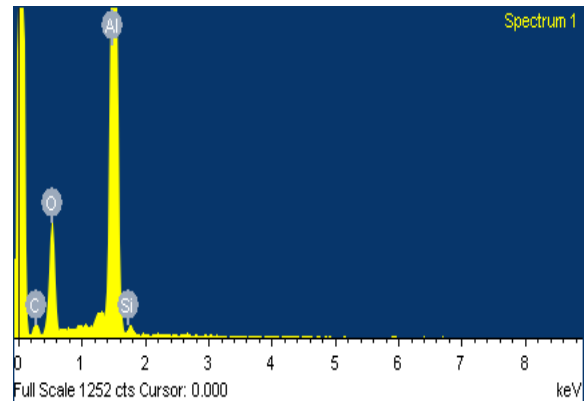**Fig.20.** The SEM of 5% CSA

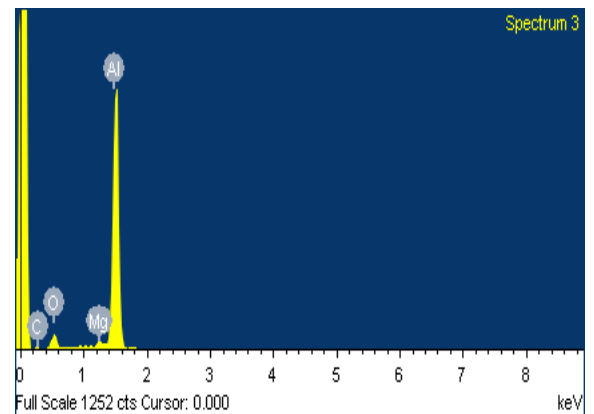**Fig.21.** EDS spectrum of Al6061

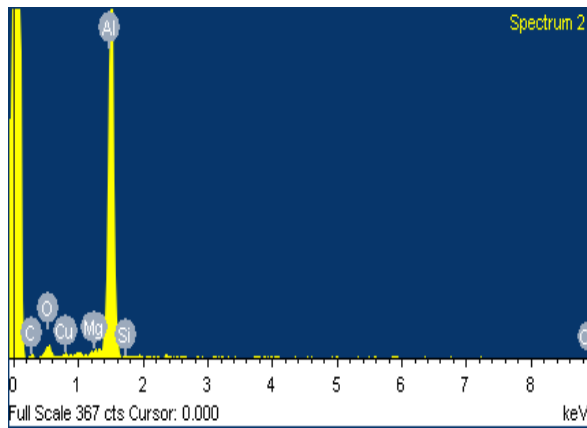
Fig.22. EDS spectrum 1% CSA
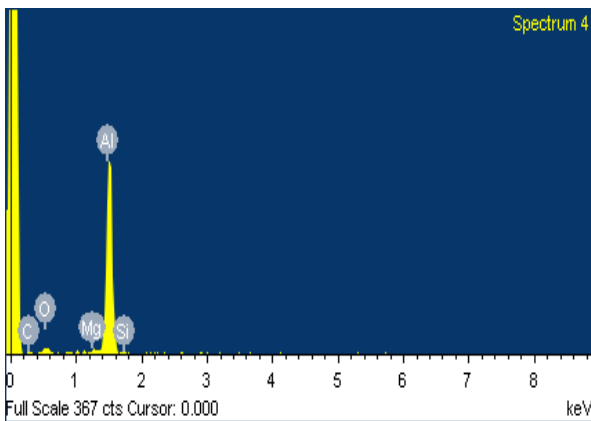
Fig.23. EDS spectrum of 3% CSA

Fig.24. EDS spectrum of 5% CSA

6. CONCLUSION

The following conclusions have been drawn:
1. The optimum conditions of the production process were that the pouring temperature was 700ºC, preheated mold temperature was 350ºC, the stirring speed was 600 rev/min, the stirring time after the completion of particle feeding was 5 min, the particle addition rate was 5g/min.
2. The density of the composites produced with only CSA as reinforcements showed an decreasing trend with the increase of the content of the reinforcements.
3. With the increase of the content of ash in the mix, the hardness increases. Similarly, the introduction of ceramic particles also increases the hardness of the composites because they act as the load bearing elements in the produced.
4. The Ultimate Tensile Strength of the composites increased with trivial with the increase of percentage of Coconut Shell Ash.

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