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Study of Physical, Mechanical and Machinability Properties of Aluminium Metal Matrix Composite Reinforced with Coconut Shell Ash particulates

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***Abstract**: The selections of materials for structural applications are done because they have a desirable combination of thermo-mechanical properties and machinability characteristics. Hybrid MMCs are the advanced engineering materials in which there are a reinforcement of two or more different materials which leads to the enhancement of physical, mechanical and machinability properties. In this view, the present analysis focuses on the study of Al-Coconut shell ash metal matrix composites. The present paper is aimed to review the enhancement in mechanical combined with physical properties and machinability characteristics of aluminium in the presence of reinforcement with Coconut shell ash (CSA). Density and hardness will be tested and in the later part analysis of machinability properties for composite. The machinability characteristics are designed by taguchi orthogonal array [L9] to determine the influence process parameters. Speed, feed rate and depth of cut are process parameters with responses are surface roughness for aluminium alloy and composite with 15% of CSA. Analysis of variance (ANOVA) is revels the best optimal condition and influence of parameters on surface roughness.*

***Keywords**: MMCs, Coconut Shell Ash, density, hardness, Surface roughness, Taguchi.*

1. Introduction

Composites are a subject of research for a number of scholars for the past many years. Many of our modern technologies invoke the requirement of materials with unusual combinations of properties that cannot be met by traditional metal alloys, ceramics or polymeric materials. Thus, a composite may be defined as a combination of two or more materials that results in better properties and characteristics than those of the individual components used alone. In contrast to the metallic alloys, each material retains its separate mechanical, chemical, physical properties. The two constituents include reinforcement and a matrix. The importance of composites as engineering materials is reflected by the fact that out of 1600 engineering materials available in the market, today a far more than 200 and still counting are composites. Composites have replaced cast iron and bronze materials at many places of application. The requirement of composite materials has gained importance and popularity in these days due to various properties like low density, good wear resistance, better hardness, good tensile strength etc.

Metal matrix composites (MMCs) are the advanced class of engineering materials in which one or more materials are reinforced in the matrix of a metal (metal matrix) in order to get a desired set of characteristics. As a result of this reinforcement, there is an improvement in the properties than the parent material's properties. These materials find its application in the automobile industry, cutting-tool making industry and in many more areas.

Aluminium based matrix composite is still the most explored metal matrix material for the study and enhancement of MMCs (Surappa et al, 2003). The reason why Al is most popular and quite attractive matrix for the metal matrix composite is due to their low density, capability to get strengthened by precipitation, good corrosion resistance, better thermal and electrical conductivities and high damping capacity.

In aluminium matrix composites (AMCs) one of the constituents is Al-alloy and is termed as matrix phase. The other constituent is embedded in the aluminium/aluminium alloy matrix which serves as a reinforcement, and usually a non-metallic component and commonly ceramic SiC and Al_2O_3. The addition

of further reinforcement materials as an additive to the combination will lead to a formation of Hybrid Metal Matrix Composites, those additives may include fly ash, coconut shell ash, rice-husk etc.
A chemical combination of silicon and carbide gives silicon carbide with a chemical formula SiC the electrochemical reaction of sand and carbon at very high temperature leads to the production of silicon carbide. There are various properties which make this compound a desirable material for our concern. Up to 1073K any acids or alkalis or molten salts do not attack silicon carbide. In the air, at 1473K, it forms a protective silicon oxide coating and can use up to 1873K. The low thermal expansion coupled with high strength and high thermal conductivities makes this material exceptionally resistant to thermal shock. Other properties include excellent abrasive characteristics and high resistance to chemical attacks.
Further, in this paper, we will come through the addition of another material, Coconut Shell Ash, a waste product. Coconut shell is an agro-based product which is available in abundance and is a potential reinforcement material. Coconut shell contains about 65 – 75% volatile material and moisture which can largely be removed during the carbonization process.
This paper represents an investigation report on the effect on properties like density, hardness and machinability on the Al-CSAp composite as compared to the Al metal.

2. Literature Review

Manoj Singla *et al.*(2009) [1] conducted an experiment on Development of Aluminium Based SiC Particulate Metal Matrix Composite. The area of concern for them was hardness, impact strength and the distribution of SiC particles in the Al sample. They observed that there was an increase in hardness as well as impact strength with the increase in the composition of silicon carbide particles. For weight fraction of 25% and grit size of SiC particles as 320, the maximum hardness is 45.5BHN and maximum impact strength is 36N-m. They also observed a homogeneous dispersion of SiC particles in the Al matrix with a declining trend in the samples prepared by with 2-Step method of stir casting technique, with manual stirring and without applying stirring process respectively.
Z. Hasan et al. (2011) [2] performed an experiment on Wear Characteristics in Al-SiC Particulate composites. In the Al-SiC composition, 2124 Al-alloy was used as the base metal with 10%wt and 20%wt Silicon Carbide particulates respectively and the composite was formed using liquid metallurgy technique. The investigation on dry sliding behaviour of the composite and the base alloy by emery papers of size 400 grit was considering. It was found that there is a significant reduction in the wear rate in the composites due to SiC particulate phase. It was also concluded that the wear rate increases with the load in all the materials studied. There is an increase in wear rate as the load gets steeper in the base alloy as compared to that of the composites.
L. Lancaster et al. (2013) [3] published a detailed study of the utilization of agro-based materials like coconut shell ash, rice husk etc as reinforcement materials. The wear, corrosion, mechanical and physical properties of the MMC was studied along with the future potential and application of agro-based waste product as reinforcement material in composites in various industrial sectors like automobile, aerospace and other sectors. It was concluded that addition of agro-based products like coconut shell ash enhanced the existing material. Further, it was concluded that these agro-based products can be used as a material of reinforcement in producing better composites to be further used in automobile, industry, construction industry and various other industries.
Ajit Kumar Senapati et al. (2015) [4] also reviewed the utilization of waste products as reinforcement in MMCs. There again it was concluded that the addition of waste product like coconut shell ash as reinforcement, the properties of the existing material got enhanced and improved.
A.Apasi et al. (2012) [5] studied the wear behavior of Al-Si-Coconut Shell Ash Particulate Composites. It was concluded that the wear rate directly proportional to the applied load while it is inversely proportional to the volume fraction of the CSAp material. It was hence concluded that due to the incorporation of the coconut shell particles in the Al-Fe-Si alloy matrix as a reinforcement material leads to the increment of the wear resistance of the material. Also, there it was concluded that the coefficient of friction is directly proportional to increasing load for the Al-Fe-Si alloy and the composites containing Coconut Shell Ash (CSAp). It was also concluded that hardness values of the composites developed are directly proportional to the percentage of CSAp additions. Further, it was concluded that a much smaller grain size in the composite is obtained as compared to the matrix alloy due to the presence of the coconut shell ash particles in the matrix alloy.
J. Saeki et al. [6] studied composites filled with coconut shell which that prepared from epoxy polymer matrix which contained up to 30 wt% coconuts shell fillers. The effects of coconut shell ash particle on the mechanical properties of the composites were investigated.
J.O. Agunsoye et al. [7] studied the effect of coconut shell ash on tribological and mechanical properties on waste aluminium cans that were recycled. The effects regarding the yield stress, strength, hardness,

impact resistance and wear resistance were investigated. The former two and the last one showed a considerable increase with the increase in amount of CSAp amount, whereas the impact resistance increased with the increase in the size of the particle.

Sandhyarani Biswas et al. [8] studied the characterization and processing of natural fiber reinforced polymer composites and concluded that there are certainly significant factors like rodent size, impact velocity and fiber loading which govern the effect of erosion wear rate in the decreasing sequence.

S.M. Sapuan et al. (2003) [9] studied the mechanical properties of composites reinforced with the coconut shell. The properties like flexural and tensile strength were investigated with three different contents of fillers, viz, 5%, 10% and 15%.

Prakash Kumar Dalai and Ajit Senapati (2014) [10] performed an experimentally based investigation of a process parameter in machining of Aluminum-based MMC. The properties of cutting force, surface roughness, ultimate tensile strength and ductility were investigated. The surface roughness, as well as cutting force, decreased with the increase in the cutting speed. Also, it was concluded that with the increase in the content of the coconut shell ash, the ultimate tensile strength increased whereas the ductility decreased in the analysis.

S.Y. AKU et. al. (2009) [11] studied the Al alloy/CSAp composite and concluded that double stir casting technique can be successfully utilized in synthesizing of al-alloy/CSAp composites. It was also concluded that the density is inversely proportional to the percentage of coconut shell in the composite. On the micro-structural level, it was observed that there is a fair distribution of coconut shell ash particle in the aluminium alloy.

Siva Sankar Raju R et al. (2015) [16] studied the optimization of machinability properties of Al reinforced with Coconut Shell Ash using Taguchi Method. In that paper, it was concluded that feed rate was the dominant parameter and then cutting speed followed by the depth of cut in the machining process of the Al-CSAp composite.

3. Materials and Methods

Materials and Preparation of Composite

The matrix metal used for the process is Aluminium (Al 1100). The material used as the reinforcement material is coconut shell ash particles of size 60µm. The fabrication is done with 15 wt% of the CSAp. In order to ensure uniform distribution of the reinforcement, the process of fabrication of composites is done by compo casting technique. The Al alloy is first cut into small pieces in order to accommodate into the graphite crucible as the alloy will be taken as in the form of an ingot. The alloy is at first in the initial stage is melted in an electric furnace. On the other hand the prepared coconut shell ash (CSAp), preheated to electric furnace temperature up to 1193K, are added to the molten metal at 973K and continuously stirred. The whole process of stirring is done at 600 rpm for around 9 min for uniform distribution of particulates in the molten metal. Thereafter, to increase the wettability small amounts of magnesium is added during the stirring process. Finally, the whole melt reinforced with CSAp is poured into the permanent metallic mould.

Measurement of density

Density is a characteristic property of a substance or material, which can be obtained by the ratio of mass and the volume. For investigating the density, two samples were taken one of the pure Al and another one Al reinforced with 15% coconut shell ash by weight. First of all, the density of pure Al sample was found in the air and then in water, and then the corresponding density of the sample was found using the formula as mentioned below.

Density of sample = (wt. in air – wt. in water)/ wt. in air.

The Same process was repeated for three readings and the values were noted and an average value was calculated giving a rough idea of about the density of the sample.

Exactly same steps were repeated to find the average rough value for the Al-CSAp sample.

The results were tabulated and comparison was done the measurement of density was done at room temperature, i.e, 273 K.

Measurement of hardness

Hardness can be defined as the measure of the resistance of a solid matter to different kind of shape change under the application of a compressive load. It may also be defined as the property of a material representing the resistance to scratching and penetration. The hardness test was done using microhardness tester with a load of 100 grams has been considered.

Metallography

The microstructure of the samples was found out under a microscopical analysis. For obtaining the microstructure the samples were cold mounted and were rubbed, in a particular manner with a controlled velocity, force and in the same direction, against the amber papers of designation 240, 320,600,800, 1000, 1400 and 1600 grits one after other respectively in an orderly manner for about 10 minutes each. After that, followed by velvet cloth minimum of 20min to obtained mirror surface finish. The sample is etched by Keller’s reagent to determine microstructure.

Measurement of surface roughness

The SURTRONIC 25 instrument was used to measure the surface roughness of the Aluminium-CSAp MMCs was done with the help of stylus instrument. The preferred direction for measuring the direction of the roughness is taken to be orthogonal to the cutting velocity vector. The analysis is done by taking the average values for the random measurements.

Taguchi method

Taguchi method is a technique which is used to predict optimal performance level based on optimal control factor level combination and experiment for confirming is conducted to verify the results of a product designed and its performance will deliver more consistent results. This experimental verification is done with the help of a systematic software technique which is based on the orthogonal array technique. The different parameters which were considered along with their levels are shown in Table 1. For the mixed levels, the orthogonal array is generated using the Taguchi L9 design. It is also further expected that the values of process parameters that are obtained from the parameter design are insensitive and are not affected by the surrounding condition of the environment.

The considered parameters include speed of cut, feed and depth of cut. The used values of these parameters are tabulated as the following.

Table1: Process Parameters and Their Levels

Parameter	Unit	(-1)	(0)	(+1)
Speed (S)	m/min	30	90	150
Feed (F)	mm/rev	0.5	1.0	1.5
Depth of cut (D)	mm	0.1	0.2	0.3

Further, in addition to this S/N analysis another analysis ANOVA (statistical analysis of variance) is performed to observe the significance of process parameters statistically

4. Results and Discussions

Density

The densities for the two samples was calculated are presented in the tabular for as below Table 1 and Table 2 respectively.

Table 2: Density table for aluminum

Sl. No.	Wt. in air (gm)	Wt. in water (gm)	Density
1.	0.9141	0.5695	0.37698
2.	0.9723	0.6087	0.37396
3.	0.8794	0.5543	0.36968
Avg. density = 0.37354			

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Table 3: Density table for Al-CSAp composite

Sl. No.	Wt. in air (gm)	Wt. in water(gm)	Density
1.	0.9236	0.5822	0.36964
2.	1.0125	0.6594	0.34874
3.	0.8752	0.5527	0.36848
Avg. density = 0.36228			

From the tables, it can be observed that for the sample of Al-CSAp composite in which Al is reinforced with 15% by wt. of CSAp, there is a decrease in the density as compared to that of considered Al sample. The consideration is done at a temperature of 273K.

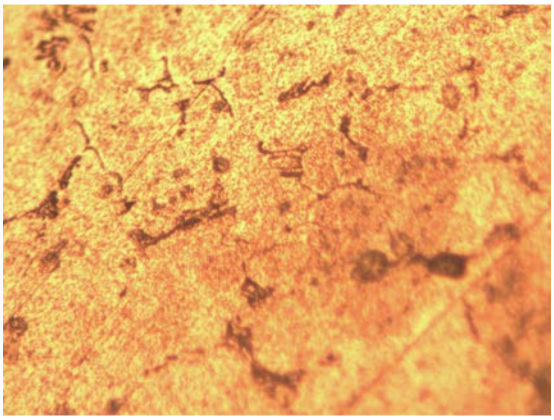

Fig 1: Microstructure of Al

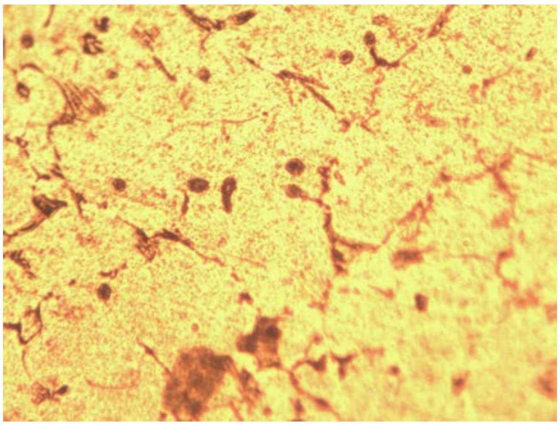

Fig 2: Microstructure of Al-CSAp composite

Using XRF analysis [16], the composition of coconut shell ash was obtained and shown in Table 4 as following

Table 4: Composition of Coconut Shell Ash

Element	SiO	MgO	Al_2O_3	Fe_2O_3	MnO	ZnO	Na_2O	K_2O
%	46	18	16	14	0.5	0.6	0.9	1.2

From the composition of CSAp it can easily be observed that when CSAp was used as a reinforcement material in Al metal, the hardness was ought to increase due to the presence of hardening elements like SiO, MgO, MnO in Coconut Shell Ash as there is a uniform distribution of CSAp in the matrix of Al (observed from the microstructure Fig 1 and 2).

Hardness

The hardness results were listed in Table 5. From the table aluminium composite exhibits more harder than base material.

Table 5: hardness number for the samples

Sl. No.	Sample	Brinell Hardness Number(BHN)
1.	Al	34
2.	Al+15%wt. SAp	46

Analysis of Variance (ANOVA)

The experiments are conducted and responses are tabulated. The parameters (cutting speed, feed rate and depth of cut) on the surface roughness of AL (R_{Al}) and AL-CSAp (R_{CSAp}) is done as shown in table 6.

Table 6: Design of experiments with responses

Run	Speed	Feed	Depth of cut	Roughness Al	Roughness Al-CSAp
1	30	0.5	0.1	2.23	1.42
2	30	1.0	0.2	2.62	1.77
3	30	1.5	0.3	3.02	2.13
4	90	0.5	0.2	2.32	1.65
5	90	1.0	0.3	2.74	1.82
6	90	1.5	0.1	2.16	1.35
7	150	0.5	0.3	2.15	1.51
8	150	1.0	0.1	1.87	1.15
9	150	1.5	0.2	2.28	1.39

Analysis of variance (ANOVA) is a statistical analysis of variance which is performed to check the significance of process parameters used in the experiment. Since minimum variance and optimum quality will be yielded when S/N ratio is highest, thus the dominant parameter can be determined from the response table for the signal to noise ratio. The response table for Al is presented in table 7 and that of AL-CSAp in table 8.

Table 7: Response table for S/N ratio of Aluminium

Level	Speed of Cut	Feed	Depth of cut
1	-8.311	-6.975	-6.364
2	-7.585	-7.519	-7.611
3	-6.415	-7.816	-8.335
Delta	1.896	0.841	1.971
Rank	2	3	1

Table 8: Response table for S/N ratio of Al-CSAp

Level	Speed	Feed	Depth of Cut
1	-4.858	-3.658	-2.289
2	-4.053	-3.792	-4.056
3	-2.551	-4.012	-5.116
Delta	2.306	0.353	2.827
Rank	2	3	1

From the response table 7, it was found that depth of cut is the dominant parameter followed by speed of cut and feed rate.

Based on the results using L9 various graphs were plotted. The graphs for main effect plot S/N ratios as well as that of main effect plots for means were plotted for each parameter against each of its levels for Al and Al-CSAp as shown in figure 4 and 5 respectively. From the response table and signal to noise ratio plots shown cutting speed (S3)(150 m/min), feed rate (F1)(0.5 mm/rev), and depth of cut (D1) (0.1 mm) which are best optimal condition of the machined surface of aluminium and Al-CSAp composite material.

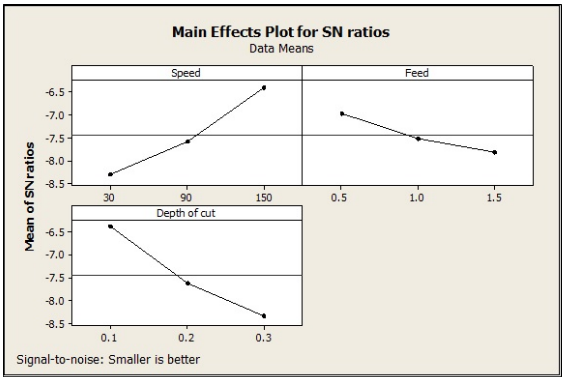

Fig 4: main effect plot for S/N ratio for aluminium

The obtained optimal process machining condition has been S3F1D1.

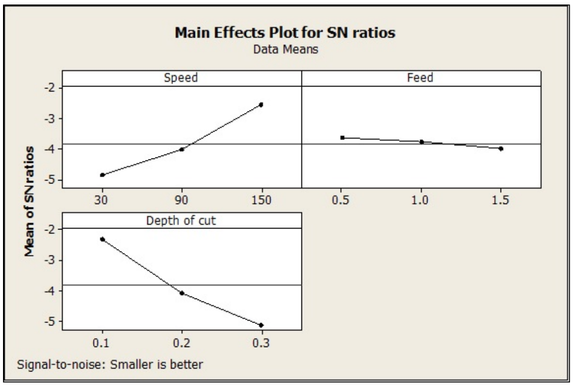

Fig 5: main effects plot for SN ratio for Al-CSAp

The ANOVA table for Al and Al-CSAp is shown as below in table 9 and table 10 respectively. The analysis tables were made considering the level confidence of 95%.

Table 9: ANOVA table for Al

Source	DF	Seq SS	Adj SS	Adj MS	F	P
S	2	5.4906	5.4906	2.74	23.75	0.040
F	2	1.0918	1.0918	0.54	4.72	0.175
D	2	5.9629	5.9629	2.98	25.80	0.037
error	2	0.2311	0.2311	0.11		
Total	8	12.776				
S= 0.3400		R^2 = 98.2%		R-sq (adj) = 92.8%		

Table 10: ANOVA table for Al-CSAp

Source	DF	Seq SS	Adj SS	Adj MS	F	P
S	2	8.2213	8.2213	4.1106	36.6	0.027
F	2	0.1909	0.1909	0.0954	0.85	0.541
D	2	12.241	12.241	6.1208	54.5	0.018
error	2	0.224	0.224	0.1122		
Total	8	20.878				
S= 0.3351		R-sq = 98.9%		R-sq (adj) = 95.7%		

From the Table 9, depth of cut is the most influencing parameter with 46.67% of contribution followed by speed and feed as 42.98 and 8.55% contribution. The ANOVA values of R^2 and R^2_{adj} is 98.2 and 92.8% for surface roughness of aluminium alloy.

From the Table 10, depth of cut is the most influencing parameter with 58.63% of contribution followed by speed and feed as 39.38 and 0.91% contribution. The ANOVA values of R^2 and R^2_{adj} is 98.9 and 95.7% for surface roughness of A-CSA composite.

Here in conducted experiment, it was observed that depth of cut is dominant parameter followed by feed rate and then the speed of cut.

5. Conclusions

The results of the investigation are presented below.

- The Al-CSAp composite exhibit harder than Al material due to the presence of hardening substances like SiO_2 and MgO in the reinforced material.
- For the considered samples of Al and Al-CSAp composite, it was found that the density of the Al-CSAp composite is less than Al alloy.
- The machining process parameters considered; speed, feed rate and depth of cut and responses as roughness for Al alloy and Al-CSA composite.
- The depth of cut is the most influential parameter out of the feed rate and speed found by ANOVA.
- The obtained optimal process machining condition has been S3F1D1. Cutting speed (S3) (150 m/min), feed rate (F1) (0.5 mm/rev), and depth of cut (D1) (0.1 mm) for surface roughness of the Al and Al-CSAp composite.

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