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Fabrication and mechanical behaviour of limonia acidissima ash – silicon carbide reinforced AL2024 alloy matrix hybrid composites

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ABSTRACT

In the present scenario, Aluminium metal Metrix hybrid composites are widely using for aerospace applications, transport applications and structural applications due to their desirable properties. In view of this, the present investigation was aimed to synthesized aluminum –silicon-agro waste based hybrid metal matrix composites. The present experiment was carried out to examine fabrication characteristics and mechanical properties of Aluminium hybrid metal matrix composite. In the present investigation, Al 2024 reinforced with silicon carbide (Sic) and Limonia acidissima ash for developing the mechanical properties. The composites were synthesized by the stir casting technique. The composites were synthesized by varying Limonia acidissima percentage of weight as 0%, 2%, 4%, 6% and 8%. The mechanical properties of Tensile strength, Yield strength, the percentage of elongation, hardness were performed. The microstructural study was carried out by SEM examination.

Keywords: *AA 2024, Silicon carbide, Limonia acidissima ash, Sieve analysis, Stir casting technique*

1. INTRODUCTION

In the modern world, there is a new era for materials having lightweight applications. In automobile industries, there is a huge demand for lightweight materials. In the past few years, aluminum alloys were promising materials used for weight reduction in automobiles. To obtain optimum performance from composite materials, there is an advantage to selecting the shape and size of the reinforcement material to fit the application. It is apparent that different material types and shapes will have advantages in different matrices.

The ever-increasing demand for low-cost reinforcement stimulated the interest towards production and utilization of silicon carbide & Limonia Acidissima (agro wastes) that contain major elements like Silicon dioxide & Aluminium oxide respectively for preparation of a metal matrix composite for rivets application. The main objective of this analysis is utilizing aero wastes for the maximum reinforcement in producing a metal matrix composite and to enhance the mechanical properties of the alloy. Moreover, it is economical and tends to effective waste management.

2. LITERATURE REVIEW

1. Shakuntala Ojha, Samir Kumar Acharya, and Raghavendra Gujjala Adding biodegradable shell particulates to an epoxy resin matrix yield superior thermal stability and mechanical properties while lowering fabrication cost.

2. Keneth Kanayo Alanemea,*, Idris B. Akintundea, Peter Apata Olubambib, Tolulope M. AdewalecThe fabrication characteristics and mechanical behavior of Al-Mg-Si alloy matrix composites reinforced with alumina (Al2O3) and rice husk ash (RHA, an agro-waste) was investigated. This was aimed at assessing the viability of developing high-performance Al matrix composites at a reduced cost. Al2O3 particulates added with 0, 2, 3, and 4 wt. % RHA were utilized to prepare 10 wt.% of the reinforcing phase with Al-Mg-Si alloy as a matrix using two-step stir casting method. Density measurement, estimated percent porosity, tensile testing, micro-hardness measurement, optical microscopy, and SEM examination were used to characterize the composites produced.

3. A. Torres and J. Miranda et al. investigated the mechanical properties of AMCs reinforced with BFS. The hardness and compressive strength of the sintering compacts were determined in order to compare the mechanical properties of the composite material. The best results concerning the AL/BFS composites reaching compressive strengths up to 370 Mpa.

4. Fabio Vigano, Andrea Manes, Marco Giglio et al. discussed the riveted joints used in aircraft structure and their

fatigue life. The squeeze force is analysed numerically on a specimen panel. A global FE model, a FE model of the joint and a complete 3D model of the rivet forming have been used in order to obtain a detailed stress state comprehensive of the residual stresses in rivet holes.

5. Aditya Jaya, Ung Hing Tiong, Reza Mohammed, Cees Bil, and Graham Clark et al. investigated the corrosion treatments and the fatigue of aerospace structural riveted joints. They discussed the effect of application on corrosion inhibited compounds on the fatigue life of riveted joints. These single lapped specimens are used in this investigation were made from 2024-T3 Aluminium alloy. The shear strength and bearing strength of this rivet grade are found to be 207 Mpa and 690 Mpa respectively. There was a transition in failure modes, from tensile failure to shear failure of the rivets.

6. Naresh Prasad, Harekrushna Sutar, Subash Chandra Mishra, Santosh Kumar Sahoo and Samir Kumar Acharya et al. investigated the Dry Sliding Wear Behaviour of Aluminium Metal Matrix Composite Using Red Mud. The effects of fillers like Red Mud on dry sliding wear behaviour of pure aluminium have been experimentally investigated. The results reveal that incorporation of red mud fillers leads to significant improvement in wear resistance of aluminium.

7. H. Binic, M. Y. Durgun, M. Kolucolak et al. investigated the effects of using blast furnace slag, ground basaltic pumice and both as fine aggregates, the durability of specimens were investigated. The maximum ultimate load was obtained in a specimen containing 5 % blast furnace slag and 5% basaltic pumice, which was 20% of larger than that of the reference concrete specimens. Specimen with high weight loss had low compressive strength, and specimens with low weight loss had high compressive strength.

1.2 Objectives of work

The objective of this study focusing on the improving various mechanical properties. Therefore, the present experimental study is to observe the machinability characteristics of Al2024+SiC+Limoniaacidissima. It also investigates the effects of various process parameters like wear characteristics, hardness, and density of an alloy material. The experimental values is simulated through ANOVA process in MINI tab software those simulated values getting in nearly my experimental values. And also study with sem analysis.

3. EXPERIMENTATION

The samples of four different compositions are prepared by pouring molten metal from the crucible into the dye. When the mixture reached 800^{o}c the crucible is taken out by switching off the equipment. The crucible is then taken out by tongs. The molten metal in the crucible is poured into dyes of required size. These dyes are fitted tight so that the molten metal does not flow out.

3.1 Material selection

3.1.1 Aluminium 2024 Alloy

Aluminum is the world's most abundant metal and is the third most common element, comprising 8% of the earth crust. The versatility of aluminum makes it the most widely used metal after steel. After iron, aluminum is now the second most widely used metal in the world.

This is because aluminum has a unique combination of attractive properties. Low weight, high strength, superior malleability, easy machining, excellent corrosion resistance and good thermal and electrical conductivity are amongst aluminum's most important properties. It possesses a density of 1/3rd of the metals like steel, copper etc.

Table 1: Typical properties of aluminum:

Density (kg/m³)	1160
Tensile strength(MPa)	70
Melting point (° C)	265
Young's modulus (GN/m²)	2.4
Percentage of elongation	90
Specific gravity	1.13
Rockwell hardness	R104
Water absorption percentage	0.60

3.1.2 Silicon carbide (Sic):

Silicon carbide known as carborundum, it is a compound of silicon and carbon with chemical formula Sic It occurs in nature as the rare mineral moissanite. Silicon carbide powder has been mass-produced since 1893 Silicon carbide is the most important abrasive and was first discovered by Acheson in 1891 while he was attempting to harden clay in a homemade electric furnace. When carbon was dissolved in molten clay, it was assumed to be a mixture of carbon and fused alumina called corundum and hence the name carborundum comes.

Table 2: Properties of silicon carbide

Molecular formula	Sic
Molecular weight	40.10gm/mole
Appearance	Colorless crystals
Odor	Odorless
Boiling point	28150C dissociates
Melting point (decomposes)	27300C
Density (all poly types)	3.21gm/cm3
Refractive index (infrared, all poly types)	2.55

3.1.3 Limonia Acidissima (Wood apple):

The wood apple is an herb with the botanical name Limonia acidissima. It has other names like elephant apple and monkey fruit. In some parts of the world, this fruit is called elephant apple because it is a favorite food of elephants, while in other areas, it gets the name wood apple because of its hard wooden shell. It is considered sacred by Hindus and is widely cultivated and eaten in India.

Fig. 1: Wood apple

Physical properties:

To assess the mechanical properties and tribological behavior of Ae-gle mar Melos, we used ball milling to crush its shell. We could then analyze the shell particles with a sieve shaker. We used those particles extracted as polymer resin filler to increase the strength of the polymer matrix. Generally, the char prepared from Aegle mar Melos shell particles are only used to remove iron and chromium from wastewater. The chemical composition of the shell particles of Aegle mar Melos fruit was 39.54% α-cellulose, 26.06% hemicellulose, and 29.86% lignin. Based on our experimental proximate analysis, the shell particles contained 19.21% carbon, 73.34% volatile matter, 0.85% ash, and 6.6% moisture. The shell particles we chose for the experiment were in the range of 1–212 m

	Flexural strength	Tensile strength	
% of filler	(MPa)	(MPa)	ILSS (MPa)
Epoxy	42.59	20.13	0.83
5	54.2	27.6	1.21
10	68.02	34.64	1.91
15	78.19	45.6	2.37
20	68.16	38.88	1.83

The actual density of wood apple shell was 1.068g/cm^3.

4. PLANS OF EXPERIMENTS

4.1. Stir casting

Stir casting is equipment which is used for casting of metal matrix composites. It is low-cost equipment, simple in operation, flexibility, applicability for large quantity production. It can be processed without using any non-conventional methods of manufacturing. But during the preparation of the composite, we have to concern about the uniform mixing of reinforcing the material in the matrix metal and also wet ability and porosity.

Fig. 2: Stir Casting Equipment

Stir casting techniques are currently the simplest and most commercial method of production of MMCs. This approach involves mechanical mixing of the reinforcement particulate into a molten metal bath and transferred the mixture directly to a shaped mold or dyes prior to complete solidification. In this process, the crucial thing is to create good wetting between the particulate reinforcement and the molten metal.
Stir casting techniques are currently the simplest and most commercial method of production of MMCs. This approach involves mechanical mixing of the reinforcement particulate into a molten metal bath and transferred the mixture directly to a shaped mold or dyes prior to complete solidification. In this process, the crucial thing is to create good wetting between the particulate reinforcement and the molten metal.

The resultant molten alloy, with ceramic particles, can then be used for die casting, permanent mold casting, or sand casting. Stir casting is suitable for manufacturing composites with up to 30% volume fractions of reinforcement. The cast composites are sometimes further extruded to reduce porosity, refine the microstructure, and homogenize the distribution of the reinforcement. A major concern associated with the stir casting process is the segregation of reinforcing particles which is caused by the surfacing or settling of the reinforcement particles during the melting and casting processes.

4.2. Sample preparation

The samples of four different compositions are prepared by pouring molten metal from the crucible into the dye. When the mixture reached 800^{o}c the crucible is taken out by switching off the equipment. The crucible is then taken out by tongs. The molten metal in the crucible is poured into dyes of required size. These dyes are fitted tight so that the molten metal does not flow out.

Fig. 3: Sample Preparation

4.3. Lathe operations:

Lathe cutting machine is used for reducing the diameter of the specimen into required specifications by using cutting tools like high-speed steels. Operations performed on the lathe are turning, facing.

Fig. 4: Lathe Operations

4.4 Tensile test:

While subjecting a prepared specimen of specified shape and size to a gradually increasing uni-axial load (force) until failure occurs, simultaneous observations are made on the elongation of the specimen. The operation is accomplished by gripping opposite ends of the workpiece and pulling it, which results in elongation of the test specimen in a direction parallel to the applied load. The ultimate tensile strength tests were done in accordance with ASTM E8-82 standards. The tensile specimens of diameter 12.5mm and gauge length 145mm were machined from the cast specimens with the gauge length of the specimens parallel to the longitudinal axis of the casting. The yield strength of the specimens was evaluated in terms of MPa.

(a) (b)

Fig. 5: Universal Testing Machine (a) Specimen before Tens (b): Specimen after Tensile Test

4.5. Preparation of aluminium-Silicon Carbide-Limonia Acidissima Ash composites:

1. Take required amount of aluminum 2024 T351 ingot.
2. Pre heats it in a muffle furnace for removing moisture content above 300℃ for about 2-3hours.
3. Also, take required quantities of reinforcement material according to the number of proportion by weighing percentage.
4. Now switch on the stir casting equipment.
5. Place the measured aluminum ingot in the crucible.
6. Aluminum will start melting in the crucible when the temperature is above the melting point of Al.
7. When the temperature of crucible attains 800℃ add reinforcement materials to the molten alloy.
8. When the mixture attains 800℃ start stirring.
9. Stir the mixture uniformly by using the stirring rod.
10. For removal of dissolved gases insert argon gas into the crucible while stirring.

Table 3: Chemical composition (wt %) of the prepared composites:

Designation	Aluminium 2024(%)	Silicon Carbide (%)	Limonia Acidissima (%)
250g AL 0gSiC 0g LAA	100	0	0
250g AL 37.5gSiC 5g LAA	83	15	2
250g AL 37.5 SiC 10g LAA	81	15	4
250g AL 37.5g SiC 15g LAA	79	15	6

5. RESULTS AND DISCUSSIONS

5.1 Tensile test results:

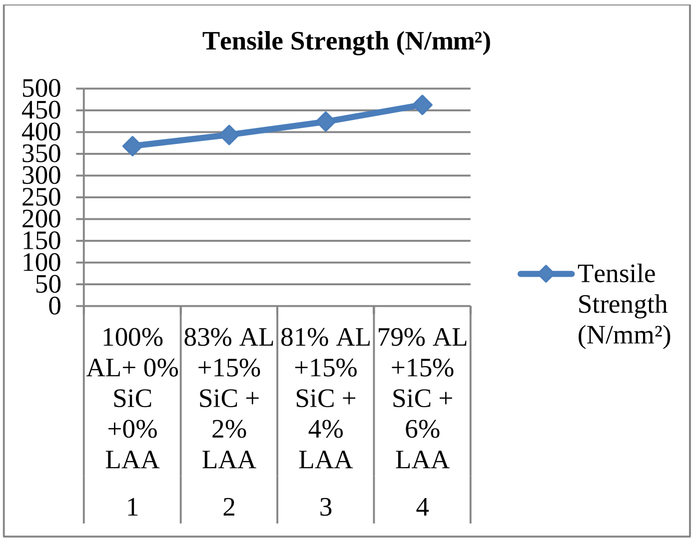
The ultimate tensile strength of AA2024 T351 is 469Mpa.

Table 4: Tensile Test Results

Sample No	Percentage of composition	Tensile strength (N/mm^2)
1	100% AL+ 0% SiC +0% LAA	367.54
2	83% AL +15% SiC + 2% LAA	393.27
3	81% AL +15% SiC + 4% LAA	423.68
4	79% AL +15% SiC + 6% LAA	462.31

A Universal Testing machine was used for testing tensile strength of specimens of above four different compositions. The specimens are prepared by decreasing Al2024 percentage of composition and increasing LAA Composition while keeping a percentage of composition of Silicon Carbide constant. The values of test results are tabulated above.

From graph 1, we can observe that there is an increase in the tensile strength of the fourth sample of composition Al79% SiC15% Laa 6%.



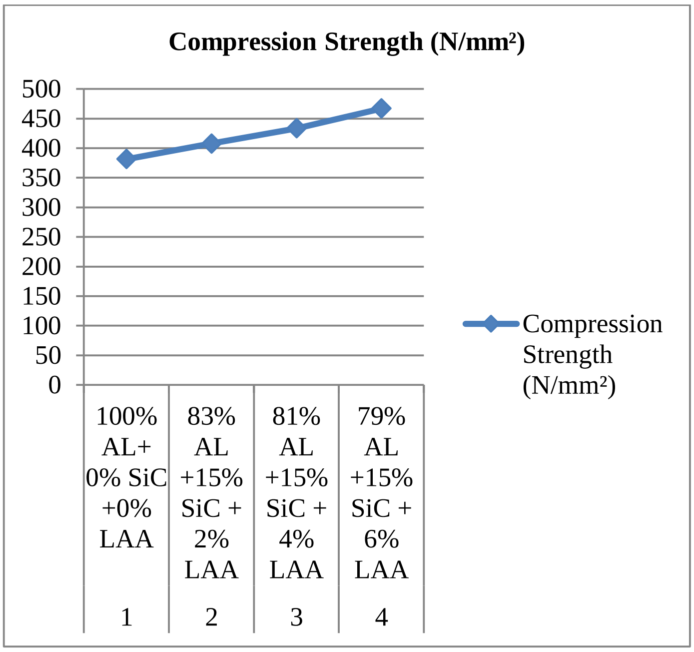
Graph 1: Tensile Strength Vs Sample Compositions

5.2 Compression test results:

The Compression Strength of AA2024 is 495 Mpa.

Table 4: Compression Test Results

Sample No	Percentage of composition	Tensile strength (N/mm^2)
1	100% AL+ 0% SiC +0% LAA	367.54
2	83% AL +15% SiC + 2% LAA	393.27
3	81% AL +15% SiC + 4% LAA	423.68
4	79% AL +15% SiC + 6% LAA	462.31



Graph 2: Compression Strength Vs Sample Composition

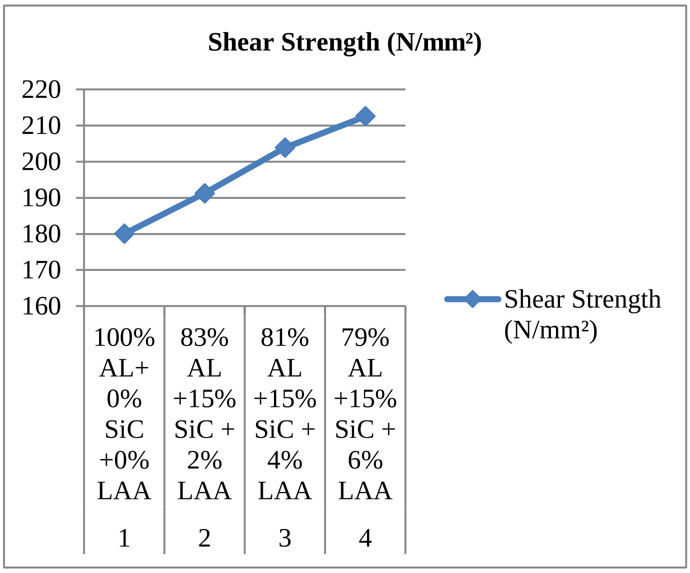
From the above graph, we can observe that there is an increase in the compression strength of the second sample of composition Al 79% SiC15% LAA6%.

5.3 Shear test results:
The Shear Strength of AA2024 is 283Mpa.

Table 5: Shear Strength Test Results

Sample No	Percentage of Composition	Shear Strength (N/mm^2)
1	100% AL+ 0% SiC +0% LAA	180.009
2	83% AL +15% SiC + 2% LAA	191.243
3	81% AL +15% SiC + 4% LAA	203.891
4	79% AL +15% SiC + 6% LAA	212.549

A Universal Testing machine was used for testing shear strength of specimens of above four different compositions. The specimens are prepared by decreasing Al2024 percentage of composition and increasing LAA Composition while keeping a percentage of composition of SILICON CARBIDE constant. The values of test results are tabulated above.



Graph 3: Shear Strength Vs Sample Composition

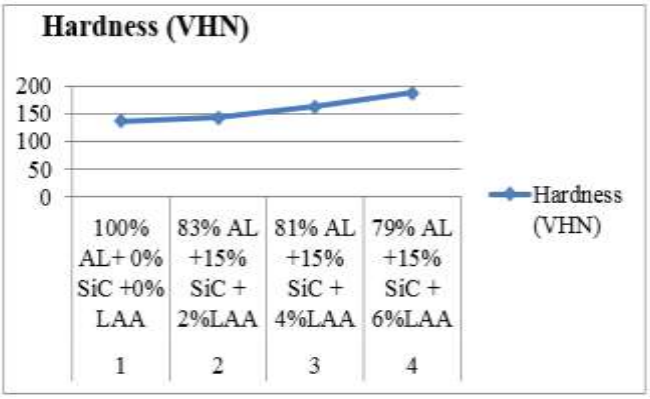
From the above graph, we can observe that there is an increase in the shear strength of the Fourth sample of composition Al79% SiC15% LAA6%.

5.4. Hardness test results:
The Vickers Hardness Number of AA2024 is 137.

Table 6: Hardness test results

Sample No	Percentage of Composition	Hardness (VHN)
1	100% AL+ 0% SiC +0% LAA	137.53
2	83% AL +15% SiC + 2%LAA	142.68
3	81% AL +15% SiC + 4%LAA	163.53
4	79% AL +15% SiC + 6%LAA	188.12

Vickers Hardness Testing machine was used for testing hardness of specimens of above four different compositions. The specimens are prepared by decreasing Al2024 percentage of composition and increasing LAA Composition while keeping a percentage of composition of Silicon Carbide constant. The values of test results are tabulated above.



Graph 4: Hardness Vs Sample Composition

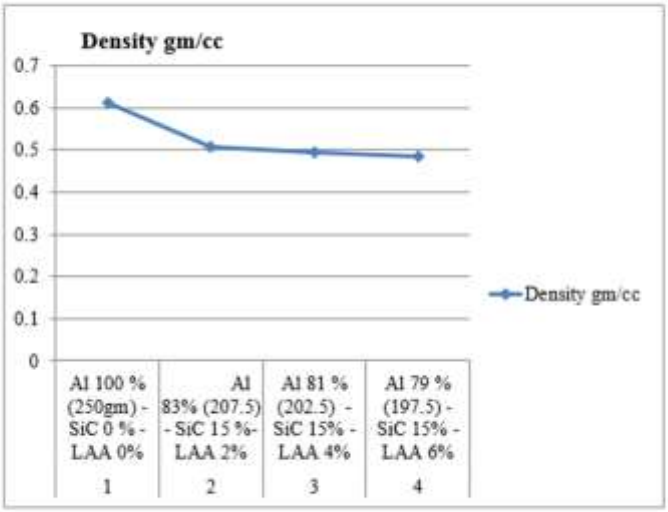
From the above graph, we can observe that there is an increase in the hardness of the Fourth sample of composition Al79% SiC 15% LAA6%.

5.5. Density test:
The density of Aluminium 2024 is 2.78 g/cc.

Table 7: Density test results

S.No.	Composition by weight percentage %	Density gm/cc
1	Al 100 % (250gm) - SiC 0 % -LAA 0%	0.612
2	Al 83% (207.5) - SiC 15 %- LAA 2%	0.508
3	Al 81 % (202.5) - SiC 15% - LAA 4%	0.495
4	Al 79 % (197.5) - SiC 15% - LAA 6%	0.483

It is observed from the graph that if the composition of Al2024 79% +SiC 15% + LAA 6% in composite increases the density decreases.



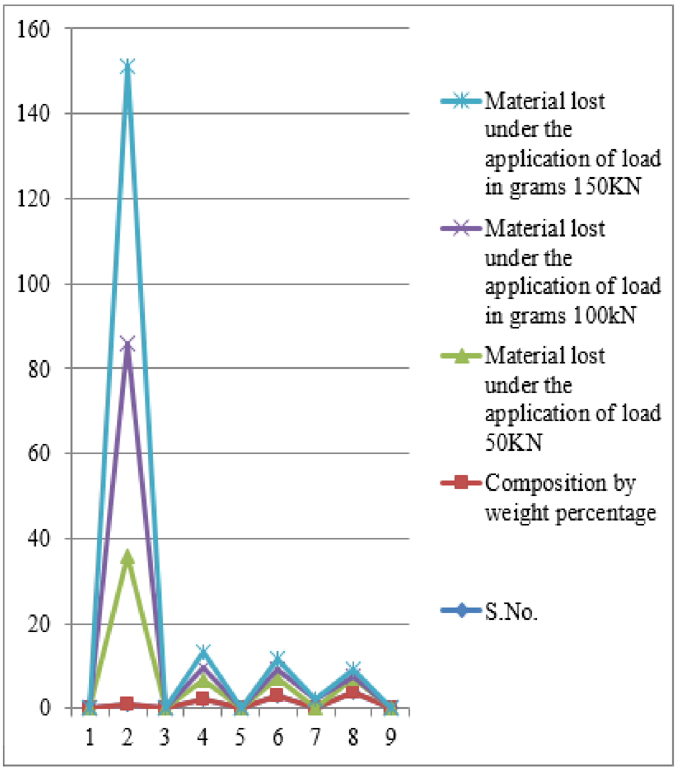
Graph 5: Graphical representation of Density values

5.6. Wear rate of composites (al2024+sic+laa)
The variation in wear rate with a load for both the Al alloy 2024 and Al 2024composite in the extruded condition. It can be seen that the wear rate of the unreinforced alloy is lower than that of the composite.

The table contains the composition by weight and material lost under a load of in grams Al2024+SiC+LAA.

Table 8: Wear rate of composites

S.No.	Composition by weight percentage	Material lost under the application of load in grams		
		50KN	100kN	150KN
1	Al 100%-SiC0%-LAA 0%	35	50	65
2	Al 83%-SiC 15%-LAA 2%	4.65	3	3.5
3	Al 81%-SiC 15%-LAA 4%	4	2	2.5
4	Al 79%-SiC 15%-LAA 6%	3	0.5	1.5



Graph 6: Representation of wear rate of composites

Figures show the material lost at different loads with varying distance. Similar graphs have generated at different a composition from that, the values have been taken of wear rate & load at different compositions.

6. TAGUCHI METHOD

Taguchi method. Generally, as three levels for three factors and one factor with two levels are considered, there can be numerous combinations of parameters because of which a number of experiments to be conducted also increase. But the specialty of the design of experiments in Taguchi method is the design of orthogonal arrays. The orthogonal arrays are Latin squares which are designed in such a way that an optimum combination of parameters can be obtained so that the optimum response characteristic value can be obtained.

6.1. S/N ratios:

Larger is better**:** This type of ratio is to be used when the response factor is desired to be maximized. For example some of the response characteristics like strength, surface finish should be maximum for any component. Hence when optimal parameters which control these response factors are to be designed, larger the better is considered.

$$\text{S/N ratio} = -10\ \log_{10}\frac{1}{n}\sum_{i=1}^{n} y_i^{2}$$

Where y_i is the observed data, n represents the number of the experiment.

Smaller-the-better:

$$\text{S/N ratio} = -10\ \log_{10}\frac{1}{n}\sum_{i=1}^{n} y_i^{2}$$

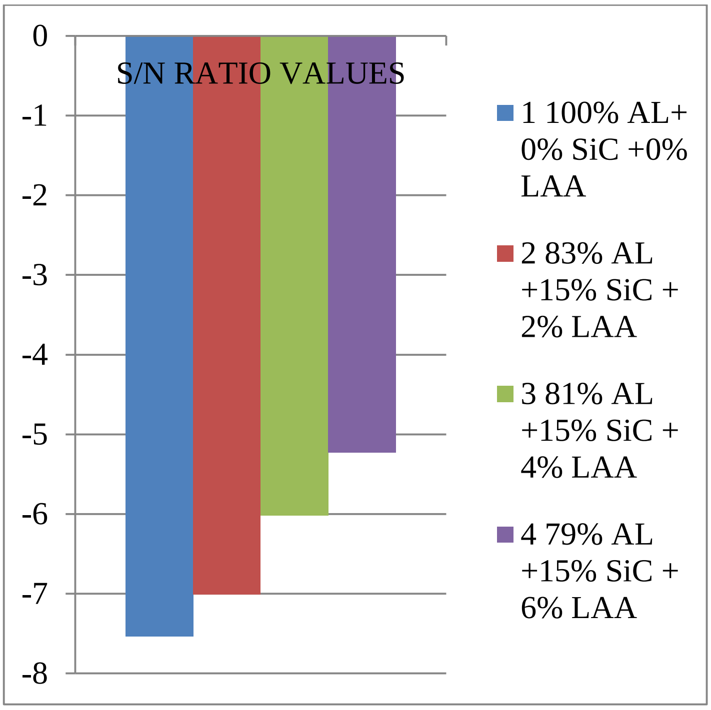
Here, n = number of the experiment of which S/N ratio is being measured
y_i= response value of the corresponding experiment

6.2. Calculation of optimization:

Table for composition by weight % and S/N ratio values the maximum optimum value is 79% Al2024-15% SiC-6%LAA.

Table 9: Composition by weight

S.No.	Composition by weight percentage %	S/N ratio values
1	100% AL+ 0% SiC +0% LAA	-7.535
2	83% AL +15% SiC + 2% LAA	-7.007
3	81% AL +15% SiC + 4% LAA	-6.015
4	79% AL +15% SiC + 6% LAA	-5.227



Graph 7: Composition by weight % and S/N ratio values the maximum optimum value

Model calculation of the optimum value

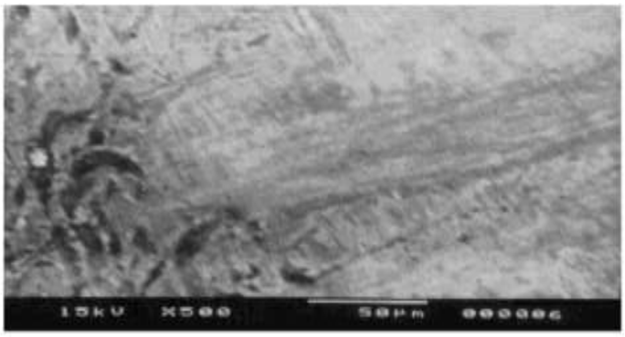
S/N ratio= $-10\ \log_{10}\frac{1}{n}\sum_{i=1}^{n}\ y_i^2$

S/N = $-10*\log_{10}((1\backslash 4)*(2.381^2+2.091^2+1.524^2+0.982^2))$

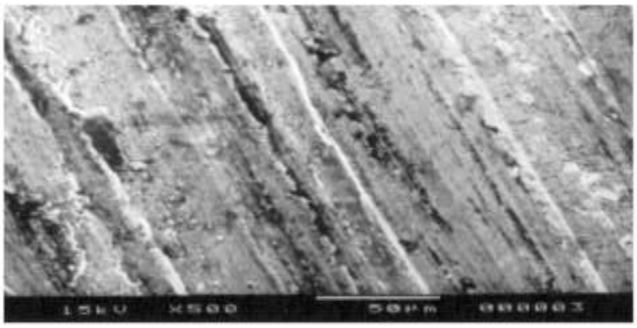
= -5.227

6.3. Microstructure Study

The SEM micrographs of the specimen surface before wear test. The specimen surface appears shining grey to the naked eye. The SEM micrograph of the specimen surface reveals that the surface is almost smooth with the minor appearance of scratches. Fig. 4(b) shows the SEM micrograph of the worn surface of 79% Al2024 -15%SiC-LAA 6%. From the SEM micrograph, it is observed that the worn surface is mainly composed of longitudinal grooves and partial irregular pits along the sliding direction. The presence of grooves indicates the micro-cutting and micro-plowing effect, whereas pits or rows are indicative of adhesive wear failure of Al2024-Sic-LAA MMC. Micro-cutting and micro-ploughing effect shows that Al2024-Sic-LAA MMC undergoes abrasive wear. Hence the wear phenomenon encountered in case of Al2024-Sic-LAA is predominantly abrasive in nature.



(a) Before Wear Test



(b) Worn Surface

Fig. 6: SEM of 79 %Al2024-15%SiC-6%LAA Specimen Surface

7. CONCLUSION

The present work has successfully demonstrated the preparation and synthesis of Aluminium Alloy 2024 reinforced with Silicon Carbide and Limonia Acidissima. Based on the results obtained it was concluded that the Agro wastes such as Silicon Carbide and Limonia Acidissima can be used as reinforcement materials to the metals to enhance mechanical properties of the material. By comparing the results obtained, 79% aluminum 15% SiC and 6% Limonia Acidissima is best suited for the practical application. The tensile Strength, Compression Strength, Shear Strength, Hardness and Wear Characteristics were tested. Results are as follows:

1. The tensile strength of AA2024 is compared with the tensile strength of composite having 79% Al2024, 15 % sic and 6% Limonia Acidissima, there is 6.01% increase in its Ultimate Tensile strength.
2. There is 36.05% increase in the Compression Strength of a composite having 79% Al2024, 15% SiC and 6% Limonia Acidissima when compared with AA202.
3. The Shear Strength of AA2024 reinforced with 79% Al2024, 15% SiC and 6% Limonia Acidissima is increased by 8.45% when compared with pure AA2024.
4. Vickers Hardness Number of the composite having 79% Al2024, 15% SiC and 6% Limonia Acidissima is increased by 4.036% when compared with pure AA2024.
5. It is observed from the graph that if the composition of Al2024 79% +SiC 15% + LAA 6% in composite increases the density decreases.
6. Wear rate of composites (Al2024+Sic+LAA) the material lost at different loads with varying distance. Similar graphs have generated at different a composition from that, the values have been taken of wear rate & load at different compositions.

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[16] Keneth Kanayo Alanemea,*, Idris B. Akintundea, Peter Apata Olubambib,Tolulope M. Adewalec The fabrication characteristics and mechanical behaviour of Al-Mg-Si alloy matrix composites reinforced with alumina (Al2O3) and rice husk ash (RHA, an agro-waste) was investigated. This was aimed at assessing the viability of developing high performance Al matrix composites at reduced cost. Al2O3 particulates added with 0, 2, 3, and 4 wt% RHA were utilized to prepare 10 wt% of the reinforcing phase with Al-Mg-Si alloy as matrix using two-step stir casting method. Density measurement, estimated percent porosity,Tensile testing, micro-hardness measurement, optical microscopy, and SEM examination Were used to characterize the composites produced.

