

Utilization of Agro-Industrial Waste in Metal Matrix Composites: Towards Sustainability

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Abstract—The application of agro-industrial waste in Aluminum Metal Matrix Composites has been getting more attention as they can reinforce particles in metal matrix which enhance the strength properties of the composites. In addition, by applying these agro-industrial wastes in useful way not only save the manufacturing cost of products but also reduce the pollutions on environment. This paper represents a literature review on a range of industrial wastes and their utilization in metal matrix composites. The paper describes the synthesis methods of agro-industrial waste filled metal matrix composite materials and their mechanical, wear, corrosion, and physical properties. It also highlights the current application and future potential of agro-industrial waste reinforced composites in aerospace, automotive and other construction industries.

Keywords—Bond layer, Interfacial shear stress, Bi-layered assembly, Thermal mismatch, Flip Chip Ball Grid Array.

I. INTRODUCTION

THE growth of world population and increase of living standard due to technology development have increased the quantity of waste materials generated through industrial, mining and agriculture activities. The waste materials are hard to disposal and thus a major concern to environmental pollution. Utilization of waste materials could reduce contamination and spaces for disposal. Therefore, recycling of waste material by converting it into green material for application in automobile and construction industries is a prime concern among the current researchers. Fly ash, red mud, palm oil fuel ash (POFA), palm oil clinker (POC), rice husks, coconut husk and sugarcane bagasse are some of the example of waste materials which have potential to be utilized in construction and automobile industries. Vast researches have been conducted but developments are still advancing for successful utilization of waste materials as partial reinforcement in composite materials. Environment friendly, energy efficient and cost-effective alternative materials produced from solid wastes will exhibit a good market potential to fulfill people's needs in rural and urban areas [1].

Composites are the combination of different materials in order to produce a new reinforced material. An interesting studied had been done toward metal reinforcements over half the decades. Although there were insufficient studies in this area, the enhancement of metal had been proved useful

especially automobile industry. A composite such as aluminium metal matrix (Al-MMCs) was produced mainly for reducing material usage since metal is quite expensive due to its limited availability in future and also the fabrication cost which is lower than conventional cost.

Al-MMCs usually incorporated silicon carbide, SiC as reinforcement into aluminium for enhancement. Moreover, the Al-MMCs offers good mechanical properties as well as tribological properties [2]. Recently studies were conducted where there are possibility of composite materials to be used to replace conventional material in automobile and construction due to similarity in mechanical properties or better, cheaper to fabricate and also lighter than pure metal.

II. POTENTIAL AGRO-INDUSTRIAL WASTE MATERIALS

A. Coconut Shell Ash

Coconut shell has little or no economic value but they are suitable for preparation of carbon black due to its excellent natural structure and low ash content [3]. Reference [4] concluded that coconut shells ash can withstand a temperature up to 1500°C with a density of 2.05 g/cm³ and it is suitable in production of light weight metal matrix composites component with good thermal resistance. Fig. 1 shows the coconut shell ash after burning. Table I shows the XRF analysis of coconut shell ash reflecting major chemical composition.



Fig. 1 Coconut Shell Ash

TABLE I
XRF ANALYSIS OF COCONUT SHELL ASH

Element	Al ₂ O ₃	CaO	Fe ₂ O ₃	K ₂ O	MgO	Na ₂ O	SiO ₂
(%)	5.45	0.57	12.4	0.52	16.2	0.45	45.05

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Reference [4] had characterized the coconut shell ash for potential utilization in metal matrix composites for automotive applications. The X-ray diffractometer (XRD) was used to identify micro structural of coconut shell ash.

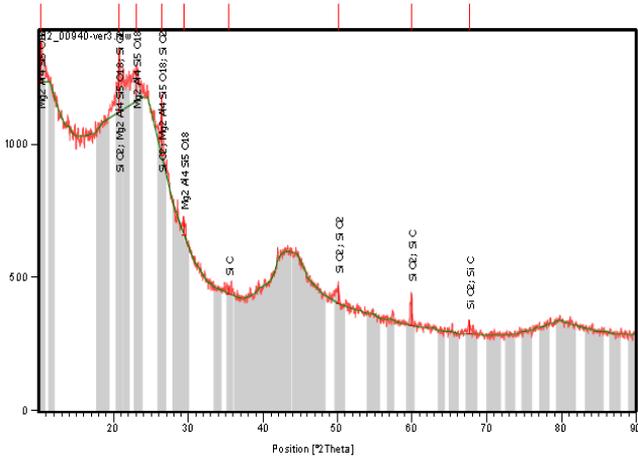


Fig. 2 XRD Pattern of Coconut Shell Ash [4]

From the micro-structural analysis in Fig. 2, the results show that SiO₂ has the highest percentage among all the compounds and elements present as shown in Table II.

TABLE II
IDENTIFIED LIST OF COCONUT SHELL ASH [4]

Visible	Ref. Code	Score	Compound Name	Displacement [°2Th.]	Scale Factor	Chemical Formula
*	00-043-0696	44	Silicon Oxide	0.000	0.912	SiO ₂
*	00-013-0294	32	Cordierite, Syn	0.000	0.594	Mg ₂ Al ₄ Si ₅ O ₁₈
*	01-089-1961	26	Quarz low Dauphinee-twinned	0.000	0.642	SiO ₂
*	01-075-1541	16	Moissanite 6\TH\RG	0.000	0.207	SiC

B. Fly Ash

Fly Ash (FA) is a particulate-reinforcement that consists of a potential discontinuous dispersoids used in metals to form composites. Cost of fly ask is quite low and it is less dense reinforcement as well. It is available in large quantities as a waste by-product in thermal power plants. Therefore, its usage in metal matrix composites is highly prevalent [5]. The major chemical constituents of fly ash are SiO₂, Al₂O₃, Fe₂O₃ and CaO [6]. Chemical composition of untreated fly ash after

sedimentation process and ball milling was evaluated and major oxides were determined using X-Ray Fluorescence spectroscopy. Major chemical compositions of untreated and treated Fly Ash are given in Table III.

TABLE III
CHEMICAL COMPOSITION OF FLY ASH

Elements	Al ₂ O ₃	BaO	CaO	Fe ₂ O ₃	MgO	SiO ₂
Before treatment (%)	29.6	0.1	0.72	3.53	0.34	64.6
After treatment (%)	25.6	01	0.69	3.14	0.56	69.5

C. Rice Husk Ash

Rice Husk Ash (RHA) is an agricultural waste and by-product of rice husk. It was estimated to produce globally 21,000,000 tonnes in 2002 and is a major seasonal environmental and health treat [7]. Rice husk ash is one of the most silica rich raw materials which containing about 90-98 silica after combustion among the family of other agro wastes. Major chemical compositions of RHA before and after treatment are given in Table IV.

TABLE IV
CHEMICAL COMPOSITION OF RICE HUSK ASH

Elements	Al ₂ O ₃	CaO	Fe ₂ O ₃	K ₂ O	MgO	Na ₂ O	SiO ₂
Before treatment (%)	4.10	0.34	0.64	2.15	0.64	0.15	91.6
After treatment (%)	3.06	0.56	0.15	2.67	0.73	0.36	91.6

D. Palm Oil Fuel Ash (POFA)

Palm oil fuel ash (POFA) is an abundant agricultural solid waste in Malaysia and it is rich in siliceous material. POFA is produced after the combustion of oil palm fiber, shell EFB and mesocarp as boiler fuel to produce steam for palm oil mill. Fig. 3(a) shows palm oil residue and Fig. 3(b) shows palm oil fuel ash after burning. The silica or silicon dioxide (SiO₂) is perhaps the most essential substance which is found in POFA which contains up to 40% [8]. Beside silica, other chemical components that detected through X-Ray Diffraction (XRD) analysis in POFA are potassium oxide, calcium oxide, magnesium oxide, aluminum oxide and andiron oxide. This interpretation was shown in Fig. 4, where silica was found at almost all major peaks [9].



Fig. 3 (a) Palm Oil Residue



Fig. 3(b) Palm Oil Fuel Ash

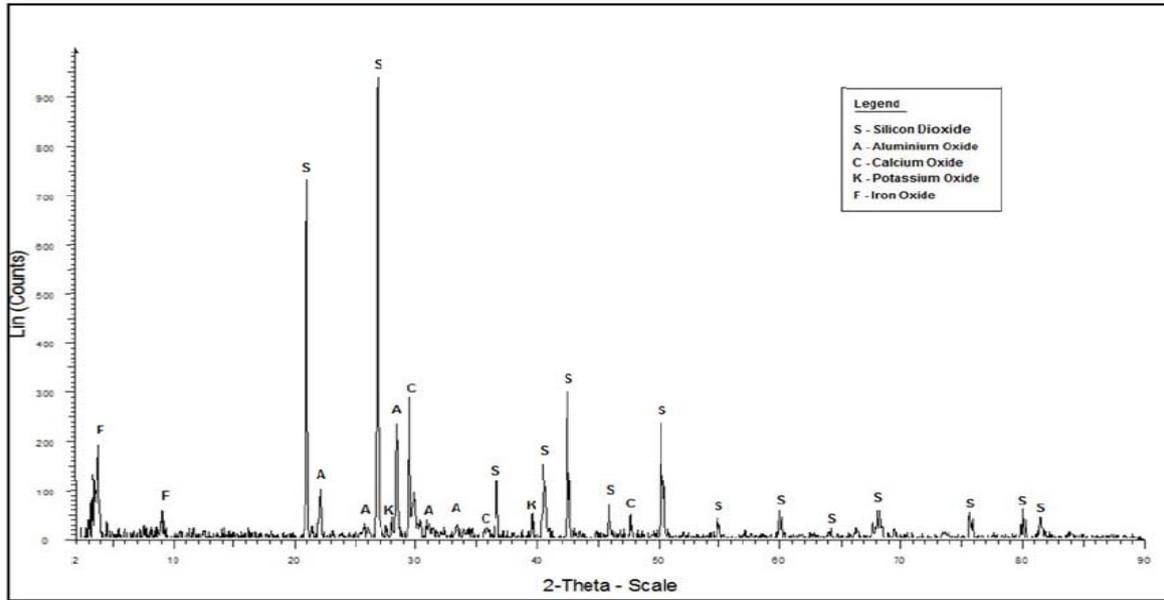


Fig. 4 XRD Spectroscopy of the POFA [8]

Table V shows the chemical compositions of POFA.

TABLE V
CHEMICAL COMPOSITION OF POFA [8]

Element	Al ₂ O ₃	CaO	K ₂ O	MgO	SiO ₂	SO ₃	P ₂ O ₅	LOI*
(%)	5.45	7.50	5.30	3.93	49.20	1.73	6.41	13.85

E. Palm Oil Clinkers (POC)

Research carried out by [10], studied on recycling soft soils with cement-Palm Oil Clinker (POC) stabilization. The authors stated that Malaysia is the largest producer of palm oil, which contributed about 50.9% of total world production. However, the extraction of this palm oil produced tonnes of waste materials known as palm oil clinkers (POC). According to [10] the forms of the clinkers are usually flaky and irregular with rough and spiky broken edges. Table VI shows the major chemical compositions of POC.

TABLE VI
CHEMICAL COMPOSITION OF PALM OIL CLINKERS (POC) [10]

Elements	Al ₂ O ₃	CaO	Fe ₂ O ₃	K ₂ O	MgO	SiO ₂	P ₂ O ₅
(%)	3.5	2.3	5.18	4.66	1.24	81.8	0.76

F. Sugarcane Bagasse

The fibrous residue of sugarcane after the crushing and extraction of its juice, known as ‘bagasse’, is one of the largest agriculture residues in the world as shown in Fig. 5 [11]. Literature reveals the versatility of the use of sugarcane residue; through its conversion inclusive but not limited to paper, feed stock and biofuel (ethanol) [11]. An analysis of SCB reveals that its main properties are cellulose, hemicellulose, lignin, ash, and wax [12]. The composition of SCB properties make it an ideal ingredient to be applied and utilised as reinforcement fibre in composite materials for the purposes of creating new materials which possess distinct physical and chemical properties. These in turn are desired for anticipated performances based on pre-set objectives. The

chemical constituent of SCB makes it an exceptional raw material for composite fabrications. The basic composition of SCB is as shown in Fig. 6.



Fig. 5 Sugar Cane Bagasse (SCB) Wastes

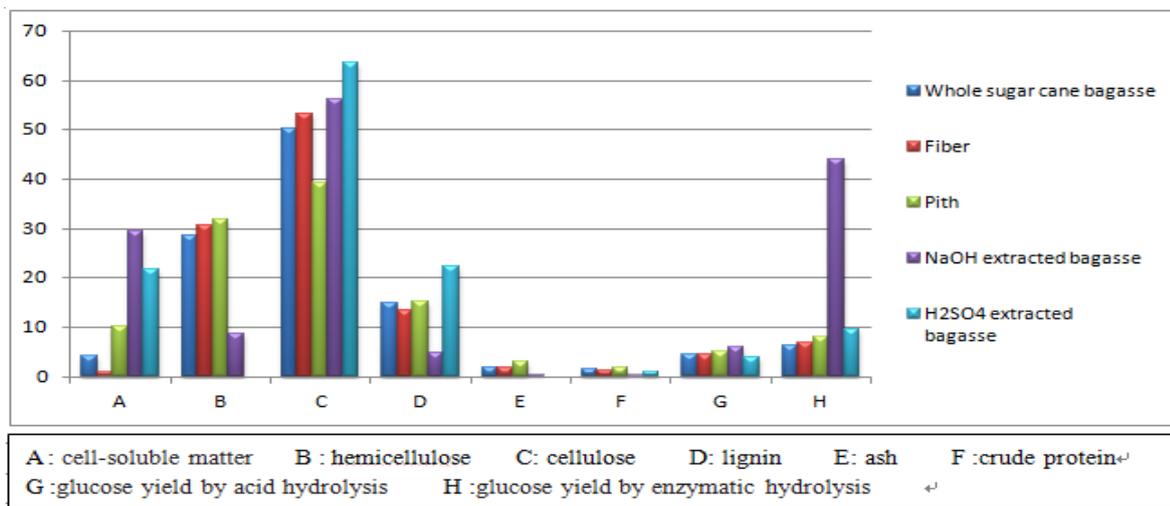


Fig. 6 Chemical Composition and Sugar Yield of Sugar Cane Bagasse and Its Fractionated Components (Percent Dry Matter) [13]

G. Maize Stalk Ash

Reference [14] had determined potentials of maize stalk ash as reinforcement in polyester composites. Maize's increasing level of production is due to an increase of the cultivated areas which determines the total amounts of waste generated by the crop after the grain have been harvested. Therefore, the waste is widely used for feeding livestock fodder and biological conversion.

The successful use of maize fibers in polyethylene matrix composite has been examined but the primary drawback is the lower processing temperature due to the possibility of lignocellulosic degradation and/or the possibility of volatile emissions that could affect composites properties [15].

Study had carried out by [16] on the use of maize fibers indicate that these fibers have the potential of being used as reinforcing fillers in thermoplastics but they has a great disadvantage of moisture absorption and poor adhesion.

III. SYNTHESIS TECHNIQUES FOR AGRO-INDUSTRIAL METAL MATRIX COMPOSITES (MMCS)

Fabrication method for composite is based on the cost, energy efficiency and performance of material produced. Stir casting method is chosen. Stir casting is the most common technique utilized for synthesizing agro-industrial waste reinforced metal matrix composites due to simplicity, flexibility and low cost. Among other techniques which are also in practice can be listed as powder metallurgy, Investment casting, Sprayed foam, Compo casting etc.

Reference [17] used stir casting method to study the mechanical properties of fly ash reinforced with aluminium alloy. Fly ash was heated up to temperature 450°C and maintained for about 20 minutes. The weighted quantity of aluminium (6061) was melted in a crucible at temperature of 800°C above its liquidus state. The molten alloy was stirred using a stirrer to create a vortex on the top surface and weighted quantity of preheated fly ash particles were added slowly into the molten alloy. Small amount of Mg was added

to ensure good wettability. Lastly, the mixed molten alloy was poured into a mould for testing preparation.

Reference [5] investigated the fabrication and characterization of Al-7Si-0.35Mg/fly ash metal matrix composites processed by different stir casting routes. Aluminum alloy Al-7Si-0.35Mg is chosen as matrix and fly ash as the reinforcement. Liquid metal stir casting, compocasting and modified compocasting cum squeeze casting are chosen for the synthesis. They found out that fly ash can be used to be reinforcement to produce Aluminum Metal Matrix Composites (Al-MMCs) but surface treatment was required to get an acceptable level of porosity and minimum agglomeration. Among three fabrication method used, Al-MMCs produced by modified compocasting cum squeeze exhibited better compressive strength than stir casting and compocasting.

Reference [2] used powder metallurgy method to fabricate the Al-MMCs reinforced with palm oil clinkers (POC) and mixed with Al particles in powder form using rotational mixing at 95 rpm for about 10 minutes. Then mixture of both materials was compacted using Universal Tensile Machine and cold pressed in a steel die with applied pressure of 250 MPa. Lastly, the cold pressed materials were sintered for 2 hours at temperature of 200°C in a carbolite furnace before pressing into a pin length 15 mm with a flat surface of 8 mm in diameter at both ends. The result of the experiment proved that the presence of palm oil clinker (POC) enhanced the wear performance of the aluminium hence acted as a solid lubricant on the contact surface of the aluminium to reduce crack propagation.

By applying the melting or powder metallurgy method on manufactured discontinuous short fiber or particle-strengthened light alloys, reuse of recycle of the composite material is possible since it can be re-melt and recast to form the composite again. Due to the density variation between the reinforcement particles and matrix metals, the composite part containing the preform will still remain its shape and sink to the bottom of the crucible during the re-melting process of composite [18].

IV. STRENGTH PROPERTIES OF AGRO-INDUSTRIAL WASTE BASED METAL MATRIX COMPOSITES (MMCS)

The multi axis surface tension in MMCs will decrease the ductility of matrix element of MMC. As the tensions and pores in matrix are increased rapidly, the formation phase of pores will be the factor to determine the ductility. Moreover, it has been stated that since these tensions and pores in matrix increase rapidly, the factor that determine the ductility is the formation phase of these pores [19].

A. Tensile strength of ALFA Composites

Reference [20] conducted research on the tensile strength of aluminium-fly ash (ALFA) composites. Fig. 7 shows that the tensile strength decreases with the increase of vol % of fly ash content at room temperature. However, at elevated temperature (at 315°C) the tensile strength increases with the

increase up to 28.9 MPa with the increase of fly ash content until 8 vol % of fly ash and the strength declines with further increase of the fly ash content. The ALFA with addition of 8 vol% of fly ash contained low volume fraction which gave the advantages of self-weight of the components, lower in weight, cost and thermal expansion but higher in abrasion resistance. It can be observed from Fig. 7 that tensile strength is similar to the base alloy for percentage of fly ash less than 8%.

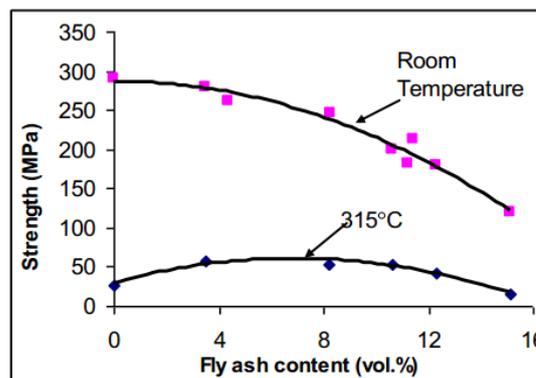


Fig. 7 Tensile Strength versus Fly Ash Content in ALFA [20]

B. Compressive Strength of POFA Concrete

Reference [21] had investigated the compressive strength of palm of fuel ash concrete. Fig. 8 shows the development of compressive strength for the concrete cubes with the different percentages of POFA replacement at different ages. It can be seen from Fig. 8 that 15% POFA in concrete mixture produces concrete strength of 48MPa which is comparable with the strength obtained by the control mixtures like ordinary Portland cement (OPC) with 5% to 15% of POFA with the increment of 5% addition in each stage.

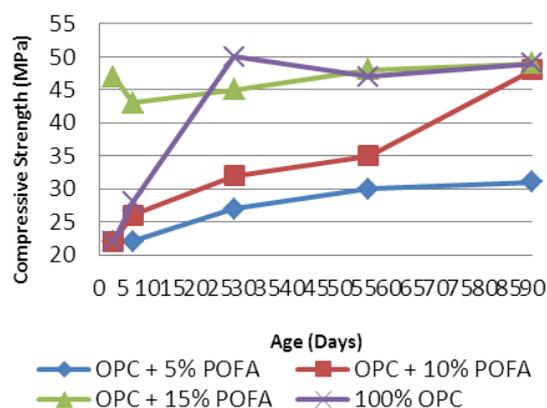


Fig. 8 Compressive Strength versus Age for Different Level of POFA Replacement

C. Hardness of Al-Bagasse Ash Composites

Reference [22] concluded that the hardness values increased with an increasing percentage of bagasse ash particle additions possibly due to the presence of hard ceramic phase of the bagasse ash in the ductile matrix (Fig. 9). As far

as hardening behavior of the composites is concerned, particle addition in the matrix alloy also increases the strain energy in the periphery of the particles in the matrix. As shown in Figure 9 below, the 10% wt bagasse ash addition to the alloy yielded the highest hardness value. As far as hardening behavior of the composites is concerned, the particle addition in the matrix alloy increases the strain energy in the periphery of the particles in the matrix and these tendencies may be due to the formation of the dislocation at the boundary of the ceramic particles by the difference in the thermo-expansion coefficient between the matrix and ceramic particles.

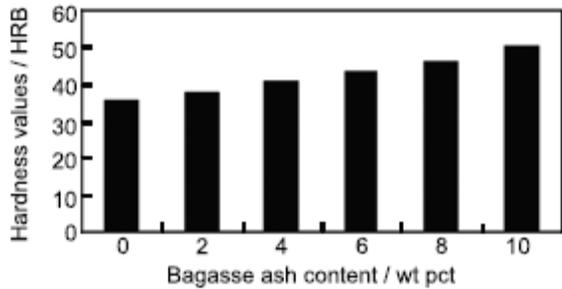


Fig. 9 Variation of the Hardness Values with Bagasse Ash Particles Addition

Reference [23] showed that increasing the percentage of fly ash, the hardness of Al composite increases distinctly with significant decrease of density as represented in Fig. 10. In other word, the hardness to weight ratio increases significantly with the addition of fly ash. At 0 wt. % of fly ash, the hardness to density ratio is 0.025. The ratio increases approximately twice as much at 15 wt. %, which is 0.047. The hardness to density ratio is a ratio used to determine the hardness of material. The harder the material is, the greater the hardness to weight ratio.

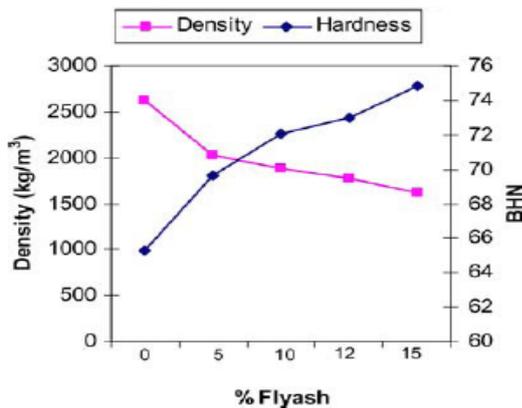


Fig. 10 Hardness and Density with Different wt Percentage of Fly Ash [23]

D. Wear behavior of Coconut Shell Ash/Composite

Reference [24] had determined the wear rate of composites reinforced with coconut shell ash particles. It was found that the wear rate decreased with an increase in the weight percentage of coconut shell ash particles (Fig. 11). And it also

increase in applied load resulted in increasing the wear rate of the composites, at lower value of the load accounts for lower wear rate. But at higher applied load, the composites got well spread with lesser particles getting exposed and the breakage of coconut shell ash particle takes place which is attributed to the extensive loss of the material due to the fragmentation of coconut shell ash particle.

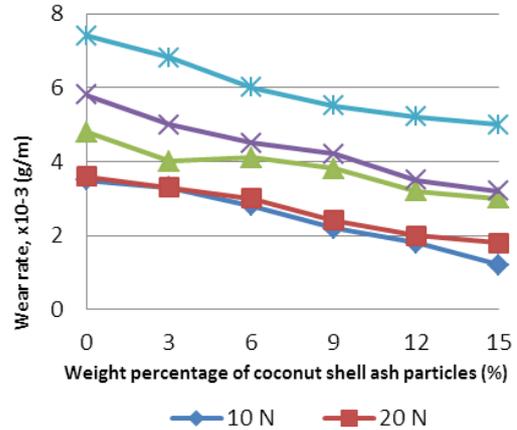


Fig. 11 Variation of Wear Rate with wt % of Coconut Shell Ash Particles [24]

Fig. 12 (a) and Fig. 12 (b) below show the variation of wear rate with sliding velocity and applied load for both unreinforced and reinforced alloy with varying percentages of bagasse ash particles reinforcement. It can be seen that adding 2 to 10 wt% of Bagasse Ash particles (BAp) in the Al-Cu-Mg alloy results in a lower wear rate. As the sliding velocity and load increases, the wear of both Al-Cu-Mg/Bagasse Ash particles composites as well as the unreinforced Al-Cu-Mg alloy increases. This was because, with higher loads contact temperature, it became high and plastic deformation occurred with consequence of very high wear [22].

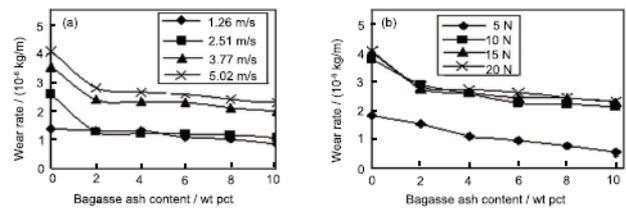


Fig. 12 Variation of the Wear Rate with Bagasse Ash Particles (a) at Constant Load of 20N (b) at Constant Speed of 5.02 m/s

Fig. 13(a) and Fig. 13(b) below showed the variation of co-efficient of friction with different applied loads and sliding velocities. The co-efficient of friction of both unreinforced Al-Cu-Mg alloy and Al-Cu-Mg/BAp composites decreases as the applied load and sliding speed increase. The co-efficient of friction increases as the amount of bagasse ash particles reinforcement increases in the alloy. When the bagasse ash particles were well bonded with the matrix during sliding, the aluminium matrix surrounding the particles were worn away which left the steel counter face and the reinforcing particles

to be effectively in contact. If the particle is easily decohesion, therefore a contact will occur between the counter face and the matrix, and the hard particles cause third body abrasion mechanism. This resulted in greater roughness and friction coefficient in reinforced aluminium alloy than unreinforced aluminium alloy [22].

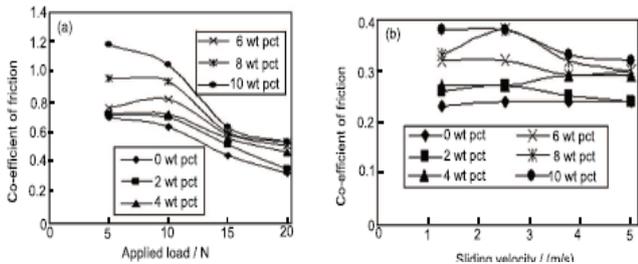


Fig. 13 Variations of Co-efficient of Friction with Applied Load (a) at Constant Speed of 5.02m/s (b) and with Sliding Velocity at Constant load of 20N

From Fig. 12 and Fig. 13 showed above, the beneficial effect of the reinforcement on the wear resistance of the composites is observed to be the best at low loads, which it reduces with increase in load applied. The beneficial effect of particle reinforcement with higher loads contact temperatures will become high and plastic deformation occurs with consequence of very high wear. The decrease in wear rate of composites may also be attributed to higher load bearing capacity of hard reinforcing material and better interfacial bond between the particle and the matrix reducing the possibility of particle pull out which may result in higher wear [22].

Reference [22] had studied the effect of bagasse ash reinforcement on the wear behavior of Al-Cu-Mg/ Bagasse ash particulate composites. The result of the research showed that Bagasse ash can be used in metal matrix composites. In view of the above description, an attempt has been made in this study to improve the dry sliding wear behavior of Al0Cu-Mg alloy reinforced with Bagasse ash particles at different loads and speeds. He observed the microstructure of aluminium matrix composites with bagasse ash reinforcement. Using Scanning Electron Microscope (SEM), the microstructure of all tested composites consisted of uniform distribution of fly ash particles within aluminium alloy matrix without voids and discontinuities which is shown in Fig. 14.

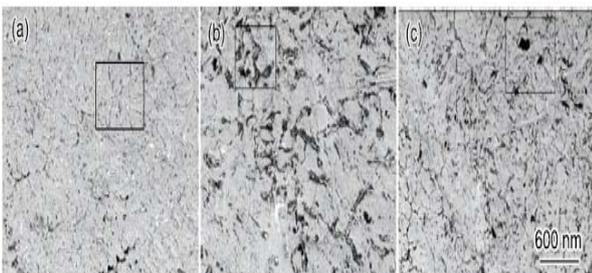


Fig. 14 Microstructure of (a) Unreinforced Al (b) Al with 4% Bagasse Ash (c) Al with 10% Bagasse Ash

Reference [2] investigated the microstructure of palm oil clinkers at different weight percentage. Fig. 15(a) and Fig. 15(b) showed flaky shape of pure Al particles and irregular shape of Palm oil clinkers (POC).

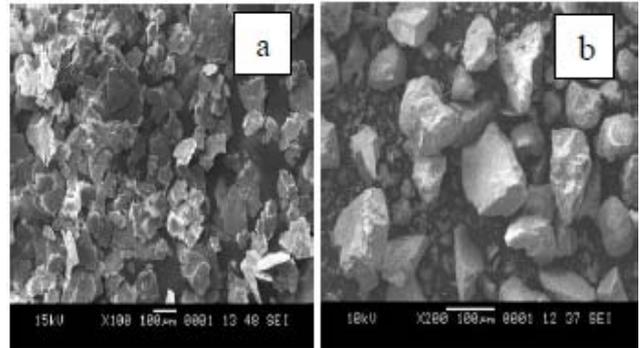


Fig. 15 SEM Micrographs of (a) Pure Al Particles and (b) Palm Oil Clinkers (POC) Particles

E. Corrosion Behavior of ALFA Composites

Reference [23] conducted experimentation on (salt spray) fog corrosion testing by exposing Al fly ash metal matrix composites to salt spray (3.5 wt. % NaCl). A fog of NaCl solution was confined in a closed chamber where the test specimens were exposed. Bubbling compressed air was created from the fog through hot deionized water and salt combination which was maintained at 50°C. The specimens were tested for 10 days. The result in Fig. 16 indicates that the corrosion resistance properties decreased with an increased in the weight % of fly ash content in Al Metal matrix. The type of corrosion to be seen was pitting corrosion. Within 24 hours of corrosion, the formation of pit can be seen clearly in the reinforced material. This was due to fly ash presence that initiated the pit. These pits initiated at flaws within the surface film and at sites of the composites where they are mechanically damaged under the conditions where self-repair could not be established. Therefore, the author concluded that the addition of fly ash particles into aluminium matrix played an important role in initiating pitting sites for corrosion to occur.

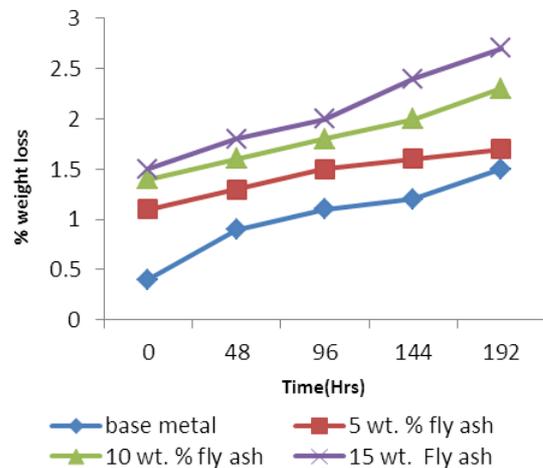


Fig. 16 Corrosion Test Results with Different Fly Ash Content [23]

F. Mechanical Properties of Maize Stalk Ash reinforced polyester composites

Reference [14] had determined the mechanical properties of maize stalk ash reinforced polyester composites. The results obtained from the mechanical tests are as shown Table VII. It can be observed from Table VII that increasing the wt % of maize stalk in the polyester results in an increased tensile, compressive, and hardness with an exception of impact strength which reduces marginally.

TABLE VII
MECHANICAL PROPERTIES OF MAIZE STALK ASH PARTICLES REINFORCED POLYESTER COMPOSITES [14]

% wt Maize Stalk Ash particulates	Tensile Modulus (MPa)	Tensile Strength (MPa)	Compressive Strength (MPa)	Impact Strength (J)	Hardness Values (HR)
0	159.55	35.10	19.12	0.90	19.70
5	203.65	39.52	20.20	0.88	26.10
10	421.74	48.50	25.50	0.87	36.30
15	794.56	50.46	29.78	0.85	48.80
20	824.62	53.60	30.32	0.78	57.80

From the Table VII as shown above, for tensile modulus and tensile strength, they are increased by increasing the weigh percent of maize stalk ash particle additions. This uniformity of maize stalk ash particle distribution has efficiently hinders the chains movement during deformation leading to high fibril orientation. This mechanism will increase the stiffness of composites as well as the tensile modulus. For the compressive strength, the increment shows that the developed composites is due to good interfacial bonding between the matrix and the uniform distribution of maize stalk ash particles, and this will lead to hardening of matrix. From the impact test carried out, the impact energy of the developed composites decreases with the addition of the maize stalk ash particle. This is because the addition of maize stalk ash will affect the energy absorption mechanism at the surface of the maize stalk ash particle and it caused the interface become not efficient. For the hardness values as shown in Table VII above, it indicates that the hardness values of the composites increases as the maize stalk ash particle are added. The increase in hardness is related with increasing amount of hard and brittle maize stalk ash particle in polyester matrix. This hard developed composited will resist deformation continuously due to indentation [14].

V. UTILIZATION OF GREEN MATERIAL AS REINFORCEMENT IN CONSTRUCTION INDUSTRIES

Reference [25] carried out the analytical and experimental studies on composite slabs utilizing palm oil clinker concrete. In this research, the palm oil clinker (POC) aggregates were used to fabricate lightweight aggregate concrete (LWAC) to replace normal concrete in composite slab. LWAC contributed to the construction for its lighter high rise building and safe disposal of waste materials. This concrete was used in the construction of composite slabs with profiled steel sheet. As a result, the LWAC slabs were lighter than the conventional concrete slabs by 18.3%. Conventional concrete slabs also had

low deflection compared to LWAC due to its elasticity. All composite slabs were considered to have ductile behavior since maximum applied load exceeded the load causing 0.5 mm end slip by 10%. This implied that POC can be adequately used in the construction of composite slabs.

Reference [26] carried out a study on new thermal insulation boards made from coconut husk and bagasse. Using hot pressing method, they developed a low density board using coconut husk and sugarcane bagasse. The authors found that the board which was measured between 0.046 to 0.068 W/mK was according to ISO 8301 standards. ISO 8301 is a thermal plane source method described in mathematical model to determine heat conductivity combined with electronics; it was almost similar to conventional insulation materials such as cellulose fibres and mineral wools. In addition, the bagasse insulation board had a density of 350 kg/m³ using pressing time of 13 minutes with the temperature of 200°C which met all the mechanical properties requirements for conventional material except for thickness swelling. The authors included that coconut husks are rich in lignin and phenolic which is found out to be an intrinsic resin in board production. Bagasse, which is the by-product of sugarcane production, on the other hand is rich with cellulose which can act as binder when producing boards. Therefore, the addition of bagasse or the rice husk had significant improvement toward existing board especially in thermal insulation application without any chemical binders.

VI. UTILIZATION OF AGRO-INDUSTRIAL AS REINFORCEMENT IN AUTOMOBILE INDUSTRIES

Reference [2] investigated the potential use of palm oil clinker as reinforcement in aluminium matrix composites for tribological applications. Samples of Al-MMCs with reinforcement of palm oil clinkers (POC) for different weight percentage of 0, 5, 10, 15 and 20 were tested. The wear behavior of composites was studied against mild steel mating surface using pin-on-disc machine at load ranging between 3-51N. Sliding distance from 0m, 100m, 200m, 300m and 500m. He used powder metallurgy method to fabricate the Al-MMCs reinforced with palm oil clinkers (POC) and mixed with Al particles in powder form using rotational mixing at 95 rpm for about 10 minutes. Then mixture of both materials was compacted using Universal Tensile Machine and cold pressed in a steel die with applied pressure of 250 MPa. Lastly, the cold pressed materials were sintered for 2 hours at temperature of 200°C in a carbolite furnace before pressing into a pin length 15 mm with a flat surface of 8 mm in diameter at both ends. He found out that the wear rate is the highest when there was no palm oil clinkers (POC) reinforcement. As the applied load increased, the wear rate increased. The wear rate was lowest when 5% weight percentage of POC content.

Reference [22] investigated the effect of bagasse ash reinforcement on the behavior of Al-Cu-Mg/Bagasse ash particulate composites. The percentage of Bagasse ash particles were varied from 0wt% , 2wt%, 6wt%, 8wt% and 10wt% to be examined on a pin-on disc test. They found that

bagasse ash can be used as reinforcement material to improve wear properties of aluminium alloy. The reinforced aluminium alloy exhibited better wear resistance than the unreinforced aluminium alloy. The wear rate was observed to be decreasing as the amount of bagasse ash increased in the alloy. The wear rate was also observed to be increasing as the sliding speed and applied load increased.

Reference [27] studied the effect of fly ash addition on the structure and compressive properties of 4032-fly ash particles composite foams. Stir casting method was used followed by direct foaming. Two types of fly ash were used, which was the micro balloons with 80 and 140 μm size and solid precipitator with 20 μm sizes. As result, they found out that the composite foam stress – strain curves exhibited typical plastic foams with higher yield and plastic stress compare to 4032 foam. However, the composite foam exhibits a lower strain-hardening exponent when compared with the unreinforced 4032 foam. He concluded that with the energy absorption efficiency of composite foam with small micro balloons reaches to 97.6% at strain of 30%, suggesting that the composites can be used in application such as packaging, impact protection and automotive bumpers.

VII. CONCLUSION

Throughout the years, many researches had been done in order to reduce the cost of producing reinforced material. With the availability of agro-waste with possible use of combining with composites, the development kept on increasing with rapid experimentation for producing the similar results as the existing material. With thorough review, following conclusions can be made:

- Addition of agro-waste such as fly ash, palm oil clinkers, palm oil fuel ash, rice husk, coconut shell enhanced the existing material.
- Agro-waste can be utilized in automotive, industrial and construction as reinforce to produce better composites.
- An estimated value of particles content needed in order to increase the mechanical properties of existing material.

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