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Development of Metal Matrix Composites and Related Forming Techniques by Direct Recycling of Light Metals: A Review

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Abstract: In this contribution, researchers have provided a summary of the agricultural and industrial waste recoveries to be deployed as the composite reinforced materials. It covers the work of previous researchers related to this area and addressed the key challenge to overcome for further development and advancement. The major contributions of this work were a comprehensive review on a wide variety of Sever Plastic Deformation (SPD) techniques implementation in development of the waste materials based reinforced metal matrix composite. The waste materials can be derived from either industrial or natural sources. Also, it discusses the range of Metal Matrix Composites (MMCs) applications in engineering and related manufacturing techniques with further emphasized on the process parameters which directly determine the material properties. Some useful suggestions were proposed to the industrialists, academicians and scientists to further improve the performance aspect of MMCs for commercialization reason. Furthermore, industrial and natural waste enhancement materials have been strongly proposed because of their higher reinforced content particulates such as alumina (Al_2O_3) and silica (SiO_2). Also, the mechanical and physical properties are directly influenced by the size, shape and weight-volume fraction of the composites as same as the potential reactions between matrixes/reinforced materials interface.

Keywords: Direct Recycling; Light Metal; Sever Plastic Deformation (SPD); Metal Matrix Composites (MMCs)

1. Introduction

Recycling of industrial wastes such as aluminium chips became a primary concern to manufacturers nowadays in an alternative method to reduce and reuse the waste materials. This could reduce the cost to produce finished goods and save the earth from harmful emissions (e.g. CO_2, CO, NO_X) as well as reducing the energy consumption in all manufacturing sectors [1]. Due to an increased awareness in renewable energy and environmental conservation, the development of new materials for engineering applications led to more composite reinforcement materials were derived from natural and industrial wastes directly without the melting. There are plenty of types of natural and industrial waste resources can be employed, however plants extracted constituents have been preferred in recent years due to the economical aspect. At present, the industrial waste of metals is also recycled and developed as MMCs. It is very important to promote more aluminium recycling by direct conversion to minimize the energy consumption and emissions which help to reduce the global warming [1].

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Table 1 - Apart of MMC applications in automobile industries [95]

Manufacturer / Company	Developed Composite	Product
Duralcan, martin, martietta, lanxide	Aluminium – Silicon Carbide	Piston
Duralcan, lanxide	Aluminium – Silicon Carbide	Brake rotors – callipers -liners
GKN, Duralcan,	Aluminium – Silicon Carbide	Propeller shaft
Nissan	Aluminium – Silicon Carbide	Connecting rod
Dow chemical	Magnesium - Silicon Carbide	Sprockets-pulleys-covers
Toyota	Aluminium - alumina	Piston rings-saffil, Aluminiumboriaw
Dupont, Chrysler	Aluminium - alumina	Connecting rod
Hitachi	Cupper-graphite	Current collectors
martin, martietta	Aluminium -TiC	Piston - Connecting rod
Honda	Aluminium - Al_2O_3-Cf	Engine blocks
Lotus Elisse, Volkswagon	Aluminium – Silicon Carbide	Brake rotors
Chrysler	Aluminium – Silicon Carbide	Brake rotors
GM	Aluminium – Silicon Carbide	Bicycle - fork brace-disk brake rotors
3M	Aluminium-Nextelf	Missile fire-aircraft electrical ac door
Knorr – bremse, kobenhavn,	Aluminium – Silicon Carbide	Brake - disc on ICE bogies
Alcoa innometalx	Aluminium – Silicon Carbide	Multichip electronic module
Lanxide	Aluminium – Silicon Carbide	PCB heat sink
Cercast	Aluminium-graphite foam	Electronic packages
Textron speciality materials	Aluminium-B	PCB heat sink

The MMCs based aluminium production by the secondary resource of solid waste in the form of chip because bonding can be easily established if the metal in micro size. Besides, Equal Channel Angular Pressing (ECAP) is introduced as a most of SPDs common method for direct metal fabrication in direct recycling [2]. ECAP process is preferable due to its potential to consolidate the chip to the magnificent level. Some studies about ECAP have been reported and focused on light metals as well as the process parameters which significantly influence the composite properties [3]. The MMCs manufactured for the purpose to achieve high potential applications in automotive industries. Among components could be manufactured are butterfly valve, engine cover, cylinder heads, engine mounting, and water pump components. Table 1 is showing a successful example of various MMCs composites. In short, this paper focuses on review of various operating manufacturing methods and propose the wide range of producing MMCs from its ore powder materials and industrial/natural wastes materials [4-5].

2. Recycling Aluminium Techniques

Fabricating of MMCs are divided into two categories known as ex-situ and in-situ assembly. The method of ex-situ synthesis the particle is added to the metal from the outside such as solid-state processing, powder metallurgy, diffusion bonding process, electroplating process, immersion plating, etc. and the in-situ synthesis the reinforced particles are reacted by exothermic reactions such as direct melting process, hot press, and reactive infiltration, etc. Table 2 shows different techniques of producing light metal composites.

Table 2 - Advanced processing methods of producing composites [2]

Mechanical Methods	Thermal/ mechanical methods	Non/ equilibrium methods	Room temperature methods
-SPD- severe plastic deformation. -ECAP -equal channel angular pressing. -HPC-high pressure torsion. -SWC- Shock wave consolidation. -TAC- Transformation assisted consolidation	-HP- Hot pressing. -HIP- Hot isostatic pressing. -HESM - Hot extrusion sintering method.	-MS - Microwave sintering -TSM Thermal spray method -PS - Plasma spraying -HVOS - High velocity oxyfuel spraying -CS - Cold spraying -SPS - Spark plasma sintering -LBM - Laser based method	-ED - Electro deposition -NCSS Nano consolidation of selfDeposition structures

3.0 Principles Composites Recycling Technique of Sever Plastic Deformation

Composites recycling techniques of SPD are developed for the purpose to enhance the material properties. Among these techniques are ECAP, Conform, accumulative roll bonding, rolling, high-pressure torsion, multiaxial deformation, Friction extrusion, twist extrusion and other methods [5-6].

3.1 ECAP Method

The ECAP method was invented by Segal in 1972. Also, the main purpose of ECAP is to induce high mechanical properties and enhance high strain into billets. ECAP is one of the methods that attract the researchers to investigate their studies which focus on light metals such as aluminium and copper or hard metals such as titanium and its metals and alloys. In addition, ECAP has become one of the most metal forming method that producing materials. And because of its superior properties it emerges from laboratories to the industrial works [7,8-9]. ECAP is an attractive process because it has the potential to produce large samples while most investigations on ECAP have concentrated on pure metals and metallic alloys, plastic deformation through ECAP [9].

Lokesh et al. [11] conducted the cast hybrid composite of samples with a diameter of 10 mm and a length of 80 mm. The product was annealed at 400 °C for 4 hours to homogenize the microstructure. Annealed composite samples were treated using ECAP die with two channels, both channels having the same circular cross-section with a diameter of 10 mm. The two channels of the model intersect at the inner and outer corners of $\varphi = 120°$ and $\psi = 12°$, respectively. According to the theoretical geometry of the mould, the effective strain is represented by a formula.

$$\epsilon_N = \frac{1}{\sqrt{3}}\left(2\cot\left(\frac{\Phi+\psi}{2}\right)\right) + \frac{1}{\sqrt{3}}\left(\psi\ cosec\left(\frac{\Phi+\psi}{2}\right)\right) \qquad (1)$$

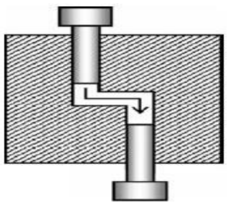
Where,

ϵ_N = the effective strain

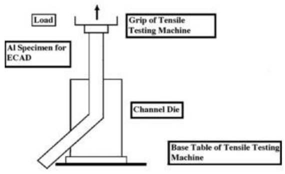
Ψ = outer angle

Φ = inner angle

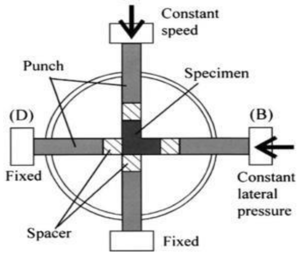
So, figure 2 shows different types of ECAP dies



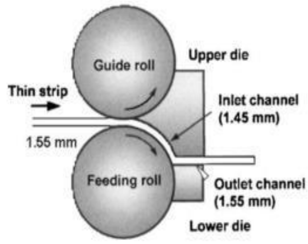
Schematic Diagram of 2 Turn ECAP Die



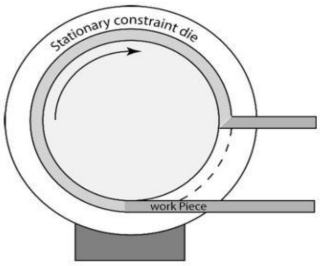
Drawing Process (ECAD)



Side-Extrusion ECAP



Continuous Production ECAP



ECAP – Conform Preocess

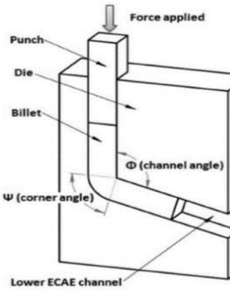


Diagram of ECAP Process

Fig. 2 - Different Types of ECAP Dies [11-12]

3.2.1 Experimental Factors Influencing ECAP Method

3.2.1.1 Outer ECAP Angle

The direct influence of the outer angle θ of the ECAP process. Xu, C et al. [14] proposed that when $\psi = 0$, the arc curvature yields to a dead zone, the billet no longer contacts the mould wall, and problems can be eliminated by the constructing a movable ECAP mould. In addition, increased enthalpy will result in less strain because it is derived from derived equations. The effects between the outer angle and the effective strain are directly performed when the internal angle of one pass and $\Phi = 90°$. The effect of equivalent strain is important in the ECAP process because the strain distribution depends on the size of the gab, and the adjustment of the internal and external angles is necessary for better prediction of the results and the final desired strain.[14]. Kačmarčik et al. [15] studied the smaller corner angle maximizes the billet uniformity while the friction reduces the corner clearance. The ECAP channel and angle have an effect on the average equivalent plastic strain. Friction has an important influence on the punch load required for extruding the blank and obtains the maximum strain at the following parameters with $\varphi = 90°$, $\psi = 15°$ and $\mu = 0.3$.

3.2.1.2 Inner ECAP Angle

The inner angle is a significant factor that enhance each transmission strain. The internal angle factor influences the development of the microstructure. The researchers propose that the angle should be chosen between 90° and 120°, and support the evidence of finite element analysis and microstructure study [16]. Shaeri et al. [17] enhanced effects on the strain distribution of ECAP under ideal conditions. Cheng Xu et al. [14] proposed that 90° is the most meaningful angle because it can achieve ultra-fine grain microstructure. The novelty of fabricating a regenerative light metal, such as a 90° bore, has obtained the best value of the large strain imposed by the ECAP method, which results in an improvement in ultrafine grain size, mechanical properties, and void elimination. Both of a Φ angle of an intersection channel and ψ curvature angle throughout the process of ECAP method. The channel was bent as the pressing die was used as a punch [17-18].

3.2.1.3 Pressing ECAP Speed

Pressing speed is an important parameter for all SPD processes. Pressure can be verified using FEM analysis and compare it with the experimental work. In addition, the experimental and simulated impact forces have the same conditions, so the finite element results are considered to be desirable [20]. When the temperature is low, high strains are needed to avoid issues related to the ductility and durability of ECAP materials and die sets [21]. In addition, large capacity hydraulic presses are required to produce higher punch speeds in the range of 1 to 20 mm/s. Studies have confirmed that the compression of pure Al has no effect on the balance of ultra-fine grains formed by the ECAP process. However, when the extrusion is at a low speed, a lower equilibrium microstructure can be produced. Other parameters directly affect the quality of attributes, not velocity and stress behaviour [22].

3.2.1.4 Pressing ECAP Temperature

ECAP temperature is a significant parameter for material consolidation process [23]. Shaeri et al. [17] proposed that when the temperature is increased from 120°C to 180°C, the precipitation and grain size were increased. On the other hand, the temperature caused by reducing the transition at high angle boundaries and metal phases. Heat the mould up to 15 minutes to obtain a temperature level. Higher temperatures level of 200°C, 250°C, and 450°C resulted in a decrease in the grain size of the microstructure during continuous ECAP process. Lower temperatures may lead to new system recovery, recrystallization, winding, and dislocation climb mechanisms becoming impossible. By lowering the temperature value, tension is required to avoid issues related to the ductility of the metal and the durability of the die of the ECAP method [23-24].

3.2.1.5 Processing ECAP Routes

The theory of deformation of the billet routes was conducted by rotating the billets through 0°, 90°, and 180° during each ECAP experiment. This method was repeated to develop the strain distribution along the intersection area, and there have been four main processing routes for studying the microstructure development during ECAP. It is recognized that after pressing, the properties of the material crystal will change due to pressing and may carry major process path definitions [25-26].

Route A: The billet is to be pressed without rotation.
Route B_A: The billet rotates 90° clockwise or counter-clockwise.
Route B_C: The billet rotates 90° clockwise between the channels.
Path C: The billet will rotate at an angle of 180°.

The ECAP route effects of light metals, including mechanical properties, microstructure, and strain evaluation [61]. However, the strain for a single pass could be calculated by Iwahashi's equation [28].

$$\epsilon = \frac{1}{\sqrt{3}}\left(2\left(\cot\frac{\Phi+\Psi}{2}\right) + \frac{1}{\sqrt{3}}\left(\Psi \csc\frac{\Phi+\Psi}{2}\right)\right) \quad (2)$$

Efficient strain through multiple passes is introduced by [29].

$$\epsilon_{eq} = \frac{N}{\sqrt{3}}\left(2\left(cor\frac{\Phi+\Psi}{2}\right) + \frac{1}{\sqrt{3}}\left(\Psi\, cosec\frac{\Phi+\Psi}{2}\right)\right) \quad (3)$$

Where

ϵ = the strain for a single pass
ϵ_{eq} = the strain for a multiple passes
Φ = inner angle
Ψ = outer angle
N = no of passes

3.2 Conform Method

It is well-known that conform principle was initially formulated by Etherington to enhance the efficiency of recycling materials. This was later developed by Segal and other researchers to improve the continuous [30]. Raab and Fakhretdinova et al. [24] have enhanced the strength and material properties of Al-Mg-Si alloy by conducting a new of multi ECAP-Conform in order to achieve stress-strain effect in material properties. Mathematical and physical modelling with Deform-3D software were applied in the demonstration to estimate the stress-strain state by multi ECAP-Conform method. Palán et al. [31] conducted an experiment of SPD Conform method with rotary swaging to produce titanium Ti grade 2. The findings found that an enhancement after the third pass of conform method which achieved 673 MPa of ultimate strength of 330nm for average grain size. The combination of both conform and rotary swaging methods results in an improvement 1070MPa of ultimate strength which causes work hardening and reduce ductility of the material. Gholami, combined ECAP with conform process to enhance the production of AA6061 ultra-fine grained. Finite Element Method ABAQUS/Explicit software to be applied. The three different type of channels (90^o, 100^o and 110^o), fraction (0.2, 0.3 and 0.4). By increasing the applied angle from 90^{o}to 110^o the amount required force reduced for about 40% and 50% respectively. Also, the coefficient friction raised from 0.2 to 0.4 causes an increases of the plastic strain force 8% to 12% [32].

3.3 Accumulative Bonding Roll Method

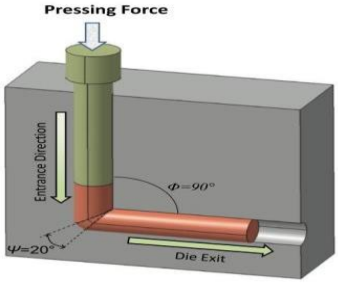
Accumulative Roll Bonding method is alternatively used to manufacture nano-structure materials [33]. Lihong et al. [34] investigated 1050/6061 aluminium surface integrity and material properties by accumulative roll bonding method. He has proposed that 1050 layers were showing coarse structure when compared to the 6061. Babaei et al. [35] applied a new concept of Accumulative Channel-Die Compression Bonding (ACCB) to demonstrate the capability of a new high strength multi-layered MMCs material Al1050/pure Cu. The findings showed that Cu layers decreased from 100μm to 4μm after six ACCB cycles and the reported data showed an increase of ultimate strength and decreases of elongation from the first cycle to the sixth process. Jamaati et al. [36] had successfully produced MMCs composites of Al/Al_2O_3 by using a low-cost technique (cold roll bonding). This is a special technique to control volume fraction of MMCs composites. The results showed that higher volume of alumina 119 HV hardness, 250 MPa tensile strength and elongation of the material are reported at 3.55% Al_2O_3.

3.4 Friction Extrusion Method

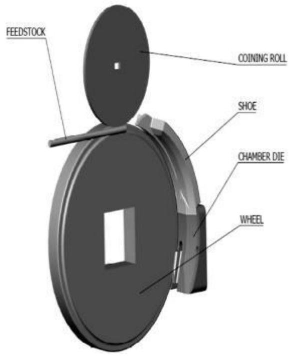
Friction technique was invented at the Cambridge UK in the year of 1990 which was derived from a stirring method to be used for forming metals, ceramics, composites or hybrid materials. Friction extrusion technique is that the friction of a wire is produced throughout the extrusion consolidation of precursor materials. Zhang et al. [37] investigated the friction extrusion process of Al6061 by CFD simulation. Viscosity, temperature, and strain rate were main parameters used to perform further investigation on velocity region, particle line, strain rates, viscosity distribution, and the deformation region to be presented. Tang et al. [38] produced consolidated wires from AA2050 alloy and AA2195 machining alloy. In his work the investigation was on the power input to the die rotational speed. He found that defects occurred by using either high or low power input die rotational speed. Microstructure considered that the average grain size was increased by increasing the die rotational speed.

3.5 High-Pressure Torsion Method

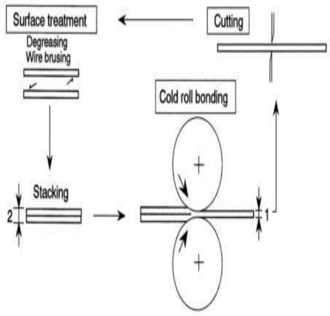
High-Pressure Torsion (HPT) was invented by Bridgman where the specimen was under the conical force to meet the virtual extension axes. It is invented in the early 1930s which became more popular technique of torsional straining hydrostatic force which introduced investigation to structural and multifunctional of the material properties [39]. Huang et al. [40] performed an investigation of tantalum metal by HTP at room temperature. He concluded that the grain size was refined at the disk edge area when the number of rotations N=0.5 as well as structure, is recovered and deformation continued. Among increasing the N from 0.5 to 5 and 10 it showed an enhancement of microstructure refinement and micro hardness while slightly get lower at where N = 10 turns. Sharmana [35]. Conducted an experiment on the Ti–6Al–4V titanium alloys by HPT method. The research presented the analysis of the material microstructure and material properties. However, the research demonstrates an important reduction of the grain size refinement, hardness and improvement of tensile strength to 1050 MPa. The demonstrated increases were 10% after HPT process.



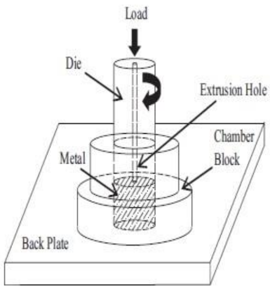
Schematic of the ECA Die process [56]



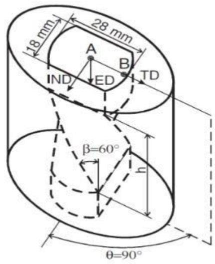
Schematic for conform process [41]



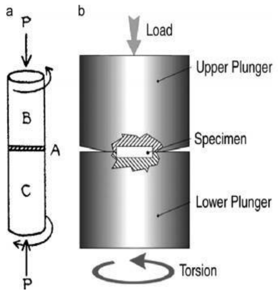
Schematic diagram of accumulative roll bonding [42]



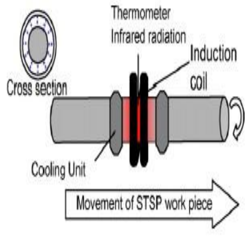
Schematic of Friction Extrusion Process [37]



Schematic diagram of twist extrusion [43]



Schematic of High-Pressure Torsion (HPT) [15]



Principle of torsion straining (STS) method [12]

Fig. 3- Different Types of SPD Methods

4.0 The reinforcement of AA6061 Metal Matrix Composites MMCs.

Chemical dissolution method was used to calculate the volume fraction for the metal matrix composites MMC Al-SiC where Vp represents the amount fraction of particulates, m_p, $r_e$present the mass and density respectively of the particles. Also, the mm and ρm represent the mass and density of the composites [44].

$$V_P = (m_p/\rho_p) / (m_p/\rho_p) + (m_m/\rho_m) \quad (4)$$

Where,
Vp = the amount fraction of particulates.
Mm= the mass of the composites.
ρm = the density of the composites

4.1 Composites From Waste Material

The general MMCs matrix affected by the size, shape and weight fraction of the reinforcement, and the potential reaction at the matrix/reinforcement interface. However, the distribution of reinforced MMCs matrix is influenced by the tendency of the materials due to the differences in the density and interactions with the solidified materials [45]. Solid wastes particles are categorised into two groups' natural wastes and industrial wastes that are going to be explained in more details.

4.1.1 Natural Waste Material

In recent years, interest in natural reinforced composites has increased dramatically. However, the amount of agricultural waste available depends on the region and country, and climate and weather also affect yield and quality. The use of agricultural waste for industrial production aims to be an economically more environmentally friendly practice and several types of agricultural waste residues are currently being used [46]. Nowadays natural resources are the main key of research to preserve the planet from the increases in the emission level that effects directly the human life. However, it is reported that unlike fossils fuel resources could reduce the effects of CO_2 as the CO_2 is released when the biomass materials are burned.

While the method of preparing natural ash such as bagasse:-

- Washing: using water to remove unwanted substances such as clay and small sand particles.
- Drying: dry in sunlight with 2-3 days after cut into small pieces and then
- Heating**:** with furnace up to 300 °C for 2-hour duration. Also, calcined to 1200 °C for about 12 hours to remove the carbonaceous substances presented by the bagasse [47].

4.1.1.1 Breadfruit Seeds Ash Particles

The African breadfruit tree is available in world countries such as Nigeria, India, and Jamaica. Atuanya had studied the fracture surface investigations of Al-Si–Fe MMCs with different volume reinforced fraction of breadfruit particles sized 500 nm using stir-casting method. By increasing the volume fraction the tensile strength and hardness were increased while grain size and impact energy were decreased. However, surface investigation proposed that there was good bonding of Al alloys with reinforced breadfruit seed ash. The authors believe that the breadfruit seed shell ash can be properly reinforced when producing lightweight MMCs with good heat resistance, so no pores and aggregates are observed in the microstructure. The researchers report that the addition of bread husk ash-reinforced materials in Al-Si-Fe alloys increase the strength of the matrix but lowers the impact energy [65].

4.1.1.2 Coconut

Coconut is one of the palm oil family which generates large amount of material waste namely as shells. It is also, one of the most common natural fibre polymer reinforced particle. Coconut shell ash combines with light metal such as aluminium to form a new metal matrix composite MMCs [66-67]. Ankesh Kumar conducted an analysis of Al-Coconut ash matrix. The findings proposed that Al-coconut ash in which reinforcement is 15%, the density was decreased compared to pure Al simple. The reported hardness results for pure Al are 34 BHN and for Al+15% composites is 46 BHN [68]. Madakson et al. [68] produced a new material metal matrix composites MMCs and coconuts shell ash was added to reinforce a low-cost MMCs and sustainable techniques to enhance automobile materials applications. Agunsoye et al. [69] investigated the reinforced polyethylene composites to produce new materials where coconut shells applied with 5%-25% volume fraction. The results shows that hardness was enhanced by increasing the reinforced percentage while modulus of elasticity, impact energy, tensile and ductility was decreased. Jain et al. [70] fabricated a low-cost matrix with coconut to form a new MMCs by stir casting. The researcher concluded that significant parameters of speed, temperature, preheating of particles, the added magnesium, blade type, mould preheating and feeding speed of steel bar have a direct impact on the material production.

4.1.1.3 Bagasse

Current trends in today's research and various discontinuous dispersions are using bagasse ash which is inexpensive and low cost wasted particulates in large amounts of solid waste originally brought from sugarcane trees. Bagasse ash has higher of silicon carbide SiC substances, which results to increase the strength of composites properties. [47-48]. Shankar et al. [47] applied sugarcane-bagasse ash as reinforced particles with aluminium alloy ($AlSi_{10}Mg$) to produce new materials composites MMCs. The volume fraction of 6, 9 & 12% with a reinforced size of (0–75 μm) of ash. The findings, tensile strength, hardness, impact strength were enhanced with increased in by increasing the volume of ash. The tensile strength with 12% of ash volume of MMCs materials reported as 10.9% higher than 0 % of ash content. The wear rate of the produced MMCs matrix was decreased with the increase of ash particles. Better results were reported 12% of volume sugarcane bagasse such as, clear interface of grooves and crack formation. Usman et al. [50] produced new materials of Al7% Si alloy, the volume fraction is varied from 0 % to 30 %. The findings found out that the density decreases from 2840.242 kgm^{-3} to 2292.208 kgm^{-3} with the minimum value at 30 % BA. the strength (UTS) varies from 139.677 MNm^{-2} to 176.683MNm^{-2} , Young modulus varies from 1429.890 MNm^{-2} to 1725.425 MNm^{-2} , impact strength varies from 75.401 kJm-2 to 128.262kJm^{-2} at the maximum fraction volume 10 % BA Hardness also varies from 70.467 RHV to 90.767 HRV with maximum value at 20% BA.

4.1.1.4 Rice Husk

Rice husk ash is a type of the natural fibre that is used to enhance light materials properties such as Al or Mg amid shelling. 78-80% of the total weight is removed as rice, the rest 20-22 % is the rice husk. Also, the 75% of total husk is a natural unpredictable material while the rest of 25% gets over into slag which as rice husk ash (RHA) [74-75]. Adib et al. [76] prepared an Al composite reinforced with rice hull ash (RHA) particles containing 3, 6, 9% RHA and 1% magnesium as a wetting agent between the matrix and the reinforcing agent by a stir casting process. Chemical analysis ash was used for the silica content and RHA was found to contain 90% silica. The results show that as the volumetric fraction of the reinforcing particles increases.

Table 3 - Variation RHA Composites [51]

Samples	Density (gm/cc)	Yield strength (MPa)	Ultimate tensile strength (MPa)	Brinell hardness (BHN)
Al	2.66	47.50	90.810	22.540
Al/3%RHA	2.52	52.0	95.70	24.680
Al/6%RHA	2.50	58.0	112.970	29.770
Al/9%RHA	2.47	61.0	115.320	33.60

Saravanan et al. [75] proposed the possibility of using rice husk ash to reinforce aluminium alloys ($AlSi_{10}Mg$) to develop new composite materials. The researcher used 6, 9 and 12% volumetric ash fraction by liquid metallurgy routes method. The results show that 3, 6, 9 and 12% of the volumetric fraction of RHA causes an increase in material properties, such as ultimate tensile strength, compressive strength and hardness of the material. Siva [77] conducted a study to form a new hybrid aluminium composite by stir casting method that reinforced ash of 5, 10, and 15% RHA and 10%SiC, 10% phosphor bronze. Al7075, RHA and SiC. The results of the tensile strength of sample A is 226 N/mm^2 and this value increases to a maximum of 310.6N/mm^2. This is due to the hardening of the aluminium alloy by rice husk ash particles.

4.1.1.5 Wood-Ceramic

Natural fibre particles play an important role in improving materials and producing large quantities of world waste that need to be recycled. However, wood-ceramics is a new area of research for today's porous carbon materials, which can be made from waste wood, such as waste wood in the wood industry, paper wood, sugar cane wood and apple pomace. As a plant, wood is an anisotropic, hygroscopic, cellular and anisotropic material containing cellulose fibres. Similarly, the manufacture of wood-based ceramics goes through three steps [45].

- Bio carbon template formed by pyrolysis of wood material.
- Infiltration of bio-carbon templates with ceramic precursors.
- Calcined to form ceramic and release organic materials.

Zhang et al. [52] fabricated WCMs/ZK60A composites and investigated its morphological properties. The findings showed an increase of compressive results from 44.9MPa of wood-ceramics to 391.8MPa for the produced composites while strength values increased from 25.60 up to 213.30 MPa. Also, Elastic Modulus composites increased twice compared to the wood ceramic material. Xian-qing et al. [53] produced inexpensive materials wood ceramics/Al (WCMs/Al) and wood ceramics/AlSi (WCMs/AlSi) by using high-pressure infiltration. The proposed findings s exhibited superior reported strength and bending strength to be conducted with infiltrated wood ceramics materials. Wood ceramic strength was reported as 18.4 MPa, WCMs/Al and WCMs/AlSi to be compared as 281.6MPa and 395.9 MPa respectively. SEM performed further investigation on fracture surfaces of material deformed metal ligaments.

4.1.1.6 Palm Oil Clinker

After palm oil is processed, the shells' ashes were conducted as energy burning substances. As a results, the waste produced by this technology clinker which has no economical values. However, researchers could use palm oil clinker waste to enhance tribological properties of MMCs composites or preserve natural aggregate to be much beneficial for construction industries [80-81]. Zamri et al. [81] investigated the palm oil clinker to produce aluminium matrix composites with various volume fraction particulates (0-20 %) which manufactured with powder technology. The researcher proposed that the composites indicate that the material exhibited better wear resistance with under different types of loads 3N, 11N and 51. It is selected Al/20 % Palm Oil Clinker Particle (POCP) shows the lowest volume loss until 500 m sliding distance. Also, SEM shows that POCP acts as solid lubricant to reduce the crack propagation at the contacted surfaces.

4.1.1.7 Ramie

Ramie is one of the most natural fibre exhibiting great material properties. It is widely used as reinforced particle as divers sporting goods, automotive, and aerospace industries. The purpose of using natural fires such as Ramie is to promote environment friendly fibres to achieve a great contribution to carbon emission reduction [82-83]. Hendra et al. [83] produced a composite of 10%, 20% and 30% Cotton-Ramie fabric/UP resin by using hand layup technique. The findings proposed that the mechanical properties such as 46.33 MPa, 57 MPa and 65.66 MPa for tensile strength are slightly increased by increasing the amount of fibre particles by 1%, 2% and 3% respectively. Also, flexural modulus and impact strength are improved by increasing the amount of volume fibre fraction. Hao Maa et al. [82] investigated the effect of linear density and yarn structure of ramine fibre yarn composite statical and dynamical properties. The findings showed that the reported maximum tensile strength of the density at about 67.3 g/cm^3. Furthermore, the interlinear fracture toughness relatively higher with lower linear density due to the bridging observation during double cantilever test.

4.1.1.8 Bamboo

Bamboo ash is offering an alternative source and lower cost to produce inexpensive reinforcement material and increase the functionality of metal engineering applications. Kumar [84]. Investigated the effects of adding of Bamboo Leaf Ash (BLA) to Al-4.5% Cu alloy which fabricated by stir casting method. The findings of surface integrity showed that the distribution of Bamboo Leaf Ash (BLA) particles was well bonded with matrix alloy composites. Also, the study observed that the density was decreased with increasing the volume fraction of BLA while the hardness and tensile were increased slightly up to (4%). BLA with further increases of the bamboo leaf ash the harness and tensile strength decreased. Olaniran O et al. [85] developed Al -6063/Hybrid Reinforcement of SiC and BSA by spin casting technique. The proposed findings were reported an enhancement of uniformly distributed particles within the matrix and the strength of the material was gradually enhanced with increasing the content of SiC and BSA until the optimum 7.5 %. However, fracture toughness was increased by increasing composite reinforcement particles but, wear resistance was improved by increasing SiC content. Daiane et al [86]. Studied the mechanical properties of hybrid composite that was reinforced with ramie natural fibres. The study focused on the effect of applying different (1% to 75%) volume fraction and (25mm, 35mm, 45mm, and 55mm) size in of the composites. 21vol % and 45mm are the optimum selected factors that directly effect on the composite mechanical and physical properties.

4.1.1.9 Rattan

Rattan is a tropical tree which is available in Asia, South America and some of tropical African countries. The slender stems 20-30 mm diameter and it is recommended material due to its lightweight, durability and flexibility. However, Rattan charcoal to be prepared in alumina crucible together with silica powder (98%) and to be burned with furnace at 1500°C for 1 – 15 hours. So, after the materials are reacted, the charcoal would convert totally into SiC [54]. Pech- Viala et al. [45] proposed that the compression and bending test results show that SiC / Al-20 at. The %Si composite was reacted for 5 hours with a bulk density of 2.3 g/cm3, an open porosity of 19%, a compressive strength of 316 MPa, and a bending strength of 138 MPa. This is because the penetration is better and the porosity of the sample becomes lower. Damfeu et al. [54] used steady-state heat transfer to study the thermal conductivity of fibres of different types of NFs. He concluded that the thermal conductivity of coconut, rattan, and kapok are 0.055 W / Mk, 0.07 W / mK, and 0.04 W / mK, respectively.

4.1.1.10 Kenaf

Kenaf is a plant which is widely grown in a variety of weather situations. Also, it has been previously used as ropes and canvas. The reason of using kenaf as a fibre reinforced particle is that it has higher rate of carbon dioxide and it is a good absorption material for nitrogen and phosphorous from the soil [88]. Kenaf is a warmseason annual fibre crop closely related to cotton and jute. At present, kenaf fibre has great potential as a raw material for composite materials. Atefi et al. [67] found that the kenaf long fibres containing rubber show a great deal of tensile strength and compressive strength. R. Yahaya et al. [55] investigated the effects of fibre orientation on the kenaf–aramid hybrid composite properties. The observation of the tensile strength and woven kenaf hybrid composites were reported at 20.78% and 43.55% higher than uni directional mat kenaf composite respectively.

4.1.1.11 Eggshell

The eggshell is a biomaterial yield to have 95% percent of calcium carbonate also 5% percent of other organic substances. The eggshells were ground and calcined at 1200°C to extract carbonized particles. The carbonized and uncarbonized substances to be added to the molten composites by stirring casting process. Hassan and Aigbodi on conducted this study and confirmed that the volume fraction of egg shell added to the

Al-Cu-Mg alloy resulted in increases of the tensile strength Al-Cu-Mg alloy values increased from 98.28 to 106.79 and 112.84 N/ Mm^2. And hardness Al-Cu-Mg/shell composite from HRC 59.12-65.41 to Al-Cu-Mg alloy 74.17 HRF [7].

4.1.2 Industrial Waste Material

Several of the manufacturing industrial methods have consisted of electric generators, plants of making steel, aluminium extraction and other thousands of tons of non-hazardous material waste that could be reused or recycled to have an alternative secondary environmental source of raw material in the world manufacturing process. Those materials such as coal, foundry sand, non-hazardous waste materials, wastes glasses, slag, dusts, mines wastes and shales. Reinforcing particulates could be used with light metal such as Aluminium to enhance its properties. Conducting industrial waste materials research leads to reduce greenhouse emissions level and contribute to a sustainable society [90-91].

4.1.2.1 Waste Glasses

Recently, the use of waste glasses as a source of replacing or enhancing composites increases the disposal costs and environmental aspects. Glasses contain a large amount of silica and alumina which cause an enhancement of the composite properties [92]. Waste glasses also could be used in the form of Mg_2Si and MgO phases throughout a solid-state reaction and to be mixed with Mg powder in order to study the findings of waste glass on enhancing material topological properties [93]. Kondoh and Tachai et al [94]. Have also proposed 360MPa of the tensile composite strength was obtained at 2 vol% SiO_2 glass powder mixture which caused in the improvement of material corrosion resistance due to its uniform Mg_2Si distribution. In the other hand, Caijun Shi et al [92]. Had investigated waste glasses to replace cement and aggregate in asphalt which has superior characteristics of work ability, strong corrosion resistance. In order to prevent corrosion of glasses and material expansion which may occur due to the cement replacement with silica fume or methacholine. According to glasses consist of SiO_2 the table shows the chemical composition of the material.

The higher content of the network formers is the higher condensation degree of the glass. The structure of glasses could be illustrated by two dimensional SiO_4 tetrahedral schematic diagram in figure 4, the components could be classified into three main groups: network formers, modifiers and intermediates.

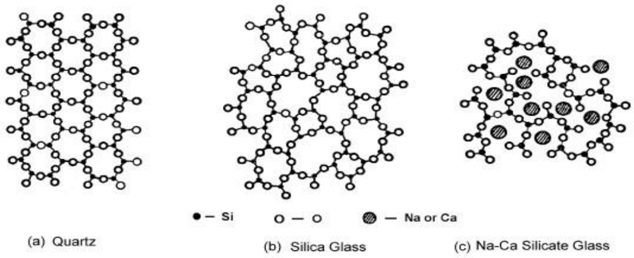


Fig. 4 - Structure of quartz, silica and Na–Ca silicate glasses [92]

4.1.2.2 Electric Arc Furnace Dust (EAFD)

Electric Arc Furnace Dust (EAFD) is one of the common processes generated from steel production. However, the availability of zinc contents gets incorporated into other materials during recycling routes process [56]. Slag and dust are obtained during the manufacturing process of steel with the method of smelting scrap metal. Thousands of tons of slag and electric furnace dusts have been yearly generated as waste products of steel manufacturing each year. Torres et al. [57] Reinforced pure aluminium with different volume fraction of GS and EAFD. He proposed the densities 2.8 to 3 g/cm^3 of all samples and compressive strength is between 225 to 370 MPa and for EAFD is between 125 to 225 MPa. He is also proposed by XRD contents are franklinite (ZnO, Fe_2O_3), cincite (ZnO) and hematite (Fe_2O_3). The chemical reactions between EAFD constituents as ZnO, SiO_2 and FeO with aluminium matrix would form the formation of matrix compounds. The chemical reactions between EAFD constituents as ZnO, SiO_2 and FeO with aluminium matrix would form the formation of matrix compounds.

$$3/2\ FeO\ s + Al\ (s)\quad 1/2\ Al_2O_3\ s + 3/2\ Fe\ (s)$$
$$3/2\ ZnO\ s + Al\ (s)\quad 1/2\ Al_2O_3\ s + 3/2\ Zn\ (s)$$
$$3/4\ SiO_2\ s + Al\ (s)\quad 1/2\ Al_2O_3\ s + 3/4\ Si\ (s)$$
$$1/2\ Fe_2O_3\ (s) + Al\ (s)\quad 1/2\ Al_2O_3(s) + Fe(s)$$

The thermodynamically considerations of the material chemical reactions during the manufacturing process at 620°C and the results showed that up to amount of 10% EAFD caused an increment of compressive strength of 248MPa and hardness of 74 HV as higher limit of increasing EAFD.

4.1.2.3 Slag

Slag is one of the iron productions generated from industries each year. Granulated blast furnace slag could be obtained by quenching molten iron slag after iron making in water or steam form to produce glasses, granular products. The process is to introduce a beneficial material to the engineering and environmental researchers. For example, 10 million tons of blast furnace slag is yearly produced by India from iron industries. Murthy et al. [97] had investigated AA2024 alloy with 5 % slag and fly ash particles by stir casting route. It is also proved that there was a uniform distribution of the slag/ash particles and causing good material bonding between matrix and reinforcement particles. The hardness of the composites was increased up to 120 VHN for 5 % slag and 124 %ash matrix. The study also proposed that increasing the number of particles would result in increasing of compressive strength of the composites. Taguchi et al. [98]. Technique conducted to obtain the optimum wear rate predicted of 0.001628 while measured wear rate 0.001841, and ANOVA concluded the sliding speed increases the wear rates material composites.

4.1.2.4 Red Mud

The source of red mud could be obtained from ore light metals process and left as solid waste materials which can cause an alternative problem to our environmental society. Because of the higher amount of ceramics constituents contained red mud. So, the researchers conducted several studies of enhancing light metal mechanical properties and overcome a problem of recycling red muds which inexpensive particles and widely used in engineering applications [99]. Karthick et al. [100] studied the effect of Aluminium 6061 matrix alloys composites that reinforced with (Al_2O_3 + red mud) particles up to 10% and fabricated by the vortex method. The findings proposed that the tensile strength and hardness increase revealed to the increase of volume fraction of the reinforced particles and reach the optimum values at 10% Al_2O_3 particles. The density measurements showed amount of porosities and increased by increasing the reinforced amount fraction of the composites. SEM also observed that dispersion of the particles was uniform with some clusters in the areas of the microstructure analysis.

4.1.2.5 Industrial Sludge

It is an automotive painting process to be generated from different types of wastes. Engine's exhaust air contains volatile organic compounds and paint sludge and huge amount to be produced were between 2555 - 4380 tons for sludgein auto manufacturing plants in order to reduce the transportation cost. So, some industrial companies dry the sludge. Paralyzed paint sludge was used by Nakouzi in the year of 1998 as reinforced materials to form a new Al matrix. Powder metallurgy route was introduced as fabrication method for this kind of research using 10 – 70 of pyrolysis sludge. The findings of MMCs noted that density was increased as the content increased from 10 – 30 and decreased above 50% [101]. Fukumoto had et al. [102] fabricated a composite material using sludge 0 – 6% alumina slug wastes and aluminium powder by spark plasma sintering method. the results proposed that sludge directly affected the material bonding strength and found that 2% sludge content is the highest value that bonding strength to be obtained at the optimum level.

4.1.2.6 Hard Particles

The purpose of recycled composites is significantly improving mechanical properties such as, tensile strength, stiffness and weight savings. In order to be compared with monolithic materials [103]. Zikin et al. [104] had performed a work of recycling NiCrBSi matrix alloy which reinforced by different types of recycled powders such as WC-Co, TiC-NiMo and Cr_3C_2-Ni. The alloy was mixed with the reinforced particles with volume fraction 60 – 40 % and also conducted erosion and wear tests for all samples. The reported findings showed that NiCrBSihard facings had average values of wear resistance. In fact, under impact test high wear resistance of the recycled composites were achieved and it was related to the microstructure images of cermet recycled reinforced particles hard facings. However, the erosion wear caused almost no dependence of the TiCNiM ore enforced coatings with the desired angles. So, both of the cases high wear resistance was obtained and hence, the double structure of hard facings of spherical type fine TiC-precipitation support the increases of the matrix alloy.

4.2 Material as Reinforcing Phase and Matrix

The improvement composites have become a major field of material science today's research. Composites (MMCs) also focus on materials specific properties, tensile strength, high-temperature and wear. However, the major challenge is to produce an enhanced composite alloy with a cost-effective. Also, one of the common used of MMCs materials are aluminium, magnesium and titanium that reinforced with typical materials such as alumina, silica, graphite, zircon, silicon carbide, boron carbide [64-74, 105].

4.2.1 Silicon Carbide SiC

SiC is widely used in engineering materials. However, the advantages are to enhance material properties [58]. Mani et al. [59] Presented the applications of sever plastics deformation consolidation of machined chips of hot forward extrusion of ECAP. It is therefore highly desirable that reinforced materials of Al-10% SiC. The findings showed that the ultimate tensile strength and ductility are 148MPa and 21.6%, respectively. An alternative findings for FE samples are 136MPa and 16.6%, respectively which shows an increase in the strength and ductility for the MMC composites which formed by FE- ECAP technique. Saheb et al. [60] studied 8% of metal matrix composites (MMC) with SiC, alumina (5%, 10%, 15%, 20%, 25%, and 30%), and 2%, 4%, and 6% graphite. And 10%. The research results show that this method successfully developed the performance of MMCs materials. The observation shows that the hardness of the fraction of the weight volume increases, the maximum hardness is 25% of the added SiC.

4.2.2 Aluminium Oxide Al_2O_3

Ceramic reinforced particles such as SiC, Al_2O_3 have many engineering advantages and engineering applications [109]. Fogagnolo et al. [6] proposed a hot and cold press process followed by extrusion to process Al_2O_3 reinforced Al6061 aluminium grade. The research results show that cold press and hot extrusion have higher profits than the main materials produced by traditional casting methods. Alumina dispersion and microstructure refinement are due to hot extrusion. Harness and tensile tests are higher than any other composites. Shima et al.

[110] studied the Al-7075 chip reinforced with 10 % Al_2O_3 particles through 20 high pressure torsion. This finding indicates that the grain size of from 8 μm to 300 nm after HTP treatment is refined and observed that the strain rate is 1.0×10^{-2} S^{-1} the micro hardness is increased from the initial value of 167HV to 260HV.

4.2.3 Boron Carbide B_4C

B_4C is an important hard ceramic material with higher properties. However, due to its low density, high abrasion resistance, high tensile strength, high melting point level, high impact level of resistance and low coefficient of thermal expansion and stable chemical stability, it is an excellent reinforcing ceramic particle for use in reinforcing composites [20,111-112]. Harichandran et al. [17]. studied the effect of adding micro-nanoB_4C boron carbide particles by using the technique of casting process. The findings proposed found that 6% amount of nanoparticles exhibited higher mechanical properties such as tensile strength, ductility level, and impact energy compared to micro-B_4C-reinforced particles. Ramnath et al [113] investigated three kinds of enhanced composites samples. Sample 1: 95% aluminium alloy, 3% alumina, and 2% boron carbide; Sample 2: 95% aluminium alloy, 2% alumina, and 3% boron carbide. Sample 3: Aluminium alloy only. The results show that due to the aluminium content, the bending and tensile strength of Sample 3 is higher than that of the other two samples [113].

4.2.4 Zircon Reinforced ZrO_2

Zircon reinforcement particle is hybrid reinforcing material with excellent material matrix, superior characteristics of wear resistance compared to as alumina Al_2O_3 [114]. Prasad et al. [115] investigated the effects of additional zircon ZrO_3 particles with aluminium that formed by a stir casting process at 750°C temperature. ZrO_2 was added until the volume fraction reached 2%, the mechanical properties were enhanced, and the strength was reported as 197 MPa, which is a higher value of the experiment, in which the purity was 64%. The reason for increasing the strength at the applied temperature of 750°C is that the dislocation density of the composite material occurred exceeds that of the zirconium particles, and the higher the dislocation density that occurs during metal formation, the higher strength. Due to the increases of the added reinforcing particles and the yield strength of the material, the hardness is relatively increased, and therefore it is reported that 88BHN at 3% of ZrO_3.

4.2.5 Fly Ash

Fly ash obtained from thermal power plants and serves reinforcements to form Al composites. Mindivan et al [116] studied the direct conversion of 6082 alloys produced with fly ash. In addition, the findings of composites such as hardness and wear resistance are significantly improved compared to conventional production. Reddy et al. [117] used powder metallurgy to produce 10% aluminium fly ash/lead metal matrix composites. The study is conducted that the powder-reinforced composite consists of 0, 5, 10, 15 and 20 % fly ash and the experiment conducted by using a mixing chamber fixed and rotating tool and a 32 rpm tool for about 1 hour, changing direction every 5 minutes to ensure proper mixing. As the amount of added material increases, the density increases directly and reaches 10% by weight of lead to decreases thereafter. Ravesh et al. [117] found that the hard conductively ash-silicon carbide as a matrix aluminium matrix composite increases with the increase in the volume of fraction and enhance the material properties. the findings of adding 2.5%, 5%, 7.5%, and 10% SiC, Rockwell hardness results are 61, 70, 81, and 93, respectively, and 5% fly ash /Al 6061 composite.

4.2.6 Fibre Reinforced

Fibre ceramics is widely used in engineering MMCs alloy matrix. However, M. Samuel performed tests involving aluminium Al-2014 reinforced with Al_2O_3 ceramic fibres by hot extrusion conversion method. The aim of the research is to produce developed materials to be used for automotive industries. The findings of 10 % Al_2O_3 ceramic fibres, the ultimate tensile strength (UTS) and yield strength (YS) were increased by 77 and 86% respectively. Also, the hardness increased by 43% and elastic modulus increased by 27% this is due to the fibres content of a very good internal cohesion [14]. Ramnath reported an overview of the investigations mechanical properties of reinforced and unreinforced AA6061 aluminium alloy. Also, channel deformation of the product at the tip of cracks in the composites material which caused the reduction of fatigue ductility [13].

5.0 Physical and Mechanical Properties

In order to enhance the material capability of various engineering applications, it is recommended to investigate its behaviour, mechanical and physical properties. It is confirmed that the combination of manufacturing techniques such as SPD and the reinforcement particles. The material enhancement material properties are related to the decrease of porosities which are shown the interaction of the material billet between the die and container [62]. Strength and ductility of microstructure analysis performance because of the synergy of fine-grained microstructure of the material examined by the SPD methods of solid-state recycling of light metal [118, 61].

5.0 Conclusion and Recommendations

In short, this review has been explored to investigate the previous researchers' works about reinforcing particles that enhanced materials properties. The reviewed articles are related to the ceramics matrixes particulates while also, introduced wasted industrial and natural materials that are used to reinforce light metal such as aluminium. Also, in this review several methods of SPD methods were preferred to be chosen for solid state recycling. Referring to the manufacturing techniques advantages and disadvantages tends to propose the right chosen method of producing MMCs from a recyclable material to the Nano-scales level. In here some of my remarks to conclude the summery proposed paper to be a guideline for other researchers.

- Recycling of light metal such as Aluminium yields to overcome our planet changes and challenges caused by the high amount of used energy for mining process. Also, secure the industrial societies of offering them an alternative of material resources.
- On the current research progress, a huge obtained demand of the Metal Matrix Composites (MMCs) of light metal development properties. Nevertheless, an attractiveness of low cost, alternative source or reinforcement particles and unique engineering applications.
- Most of the reinforcement materials contain several carbides, and oxides particles such as SiC, B_4C, Al_2O_3, ZrO_2, SiO_2, and MgO. Which modify the art of reinforcing phases of the Metal Matrix Composites.

Several manufacturing metal forming techniques have been discussed in this review to propose the suitable manufacturing method for MMCs productions. However, SPD shows a superiority of an ultra-fine strain to be imposed of a bulk metal which results to form an ultra-fine grain materials. ECAP is one of the best method to be obtained because of its large production level and its multi-passes of the material enhancement and simple's sizes [121].

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Table 4 - Shows the Techniques Advantages / Disadvantages of Producing Light Metal Composites

No	Fabrication Method	Concept	Advantages	Disadvantages	Ref
1	Powder metallurgy	• Powder metallurgy presented process as the conversion of chips into powder by ball-milling to obtain the powder then cold press is used to produce billets and extrude with or without reinforced particles. • Three main mixing powder and compaction to form the green -state of the sintering process.	• Able to form complex items • The tolerances is close to economic benefits • Lower cost – higher volume of production. • Fatigue is improved by increasing the densities which results in higher performance.	• With sintering method particles are broken into pieces during the compaction process. That could not maintain the hollow shape	[62] [63] [45]
2	Stir casting	• Stircasting is known to be a preferredmethods for forming of aluminium matrix due to its simplicity and ability to manufacture composites materials.	• Simple to manufacture and economically - superior quality best amongst the various processing technique. • Two-step processing	• Stir-casting limits the fabrication of MMCs materials up to 30% by volume.	[45] [64] [20] [65]
3	Pressure infiltration	• Different shapes of liquid infiltration that utilizes pressure inner gas to force the material which in liquid form to final product.	• It is used for forming MMCs materials that contain particulate fibre reinforcement. • Control pressure makes that possible tp form in low strength moulds with higher infiltration pressures short times	• Non-uniform distribution of the reinforced particles due to density level the mismatch of matrix and filler material.	[66] [45] [67]

4	Squeeze casting	The external pressure of molten metal to be conducted with gravity casting, squeeze casting technology facilitates results in higher structural uniformity and has the smallest possible porosity, good interfacial bonding, and fairly uniform distribution.	• Good compatibility of materials and the particulates • Enhancement of the materials alloys • Filled with of hollow particles of the FA with materials	• cast defects like pores	[68] [69]
5	Capillary drive or pressure less infiltration	According to the driving force, the infiltration process can be divided into three categories: (I) external pressure assistance, (II) vacuum actuation and (III) capillary actuation or less pressure.	• Make complex shaped components • The process is quick	• Expensive tools and difficulties in making moulds	[68] [45]
6	Compo casting technique	The composite casting process is a stirred stirrup reinforced in a semi-solid state with low Mg ignition and oxidation potential.	• Clean interface between MMCs • Excellent performance • Simple manufacturing process	• High/medium processing costs	[70] [67] [2]
7	Friction stir welding method	Existing process technology for forming surface composites	• An attractive fusion welding has a significant potential to bond Al composites with higher strengthen joints	• High/medium processing costs • FA deformation or fracture (especially for hollow fly ash	[2] [71]
8	Cavitation based on ultrasonic cavitation	Melt processing technology for metal substrates compared to mechanical alloying Nanocomposites (MMNCs) involve stirring ceramic particles into the melt	• Good matrix particle bonding for easier control of matrix structure • Low processing costs. • Manufacturing Mixed MMC Composites for electrical applications	• Poor to form complex shapes	[72]

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Table 5 the observation of fabricated MMCs by ECAP process

No	Matrix	Fabrication Method	Inner and Outer Diameter	Reinforced Materials and vol % fraction	Observation	Reference
1	Al -A356 alloy	ECAP	-	-	Al (A356) had been studied by solid-state recycling in order to enhance strain, stress and microstructure grain size which utilized by ECAP process.	[73]
2	Al–SiC	ECAP + stir casting technique	Φ = 120° Ψ = 0°	5, 10.% of silicon carbide SiC with 30 lm particulate	MMC metal matrix composites of Al-SiC as reinforced with 5-10 % SiC (30 µm) particulates by ECAP + stir casting technique. The grain size of the MMC was minimised from 45µm to 8µm after two passes in Al-5 %SiC composites. 45µm to 16µm after one passes which exhibits overall improvement of the material properties.	[44]
3	Al-6082 alloy	ECAP	Inner angle Φ= 0° Outer = 90°	-	The study presents the flow stressed of nanostructured Al-6082 by using ECAP method. Also, the flow stress depends on the number of passes and the direction of the die axis. The study proposed that the highest hardening strain was obtain at an angle of 90°C.	[74]
4	Al-Si-SiC	stir casting	-	Si 1, 2, 3 and 4 %, and SiC silicon carbide of 0.5, 1, 1.5 and 2.0 %.	The paper investigated the difference of Si and SiC on the material properties pf Al-Si-SiC. With increase both silicon and silicon carbide exhibit an increases of both yield strength, ultimate tensile strength, and elastic modulus but, decreases the material ductility.	[75]
5	Al-Al_2O_3	(ECAP) + extrusion		5.% nano-Al_2O_3	ECAP and extrusion were conducted to consolidate Al and 5% of nano-Al_2O_3	[76]

					material. The study proposed, three passes of ECAP capable to consolidate 99.29% of the density. However, the overall materials exhibit better material properties results such as wear resistance.	
6	Al - CNTs	ECAP	Φ = 120° Ψ = 20°	2 % carbon nanotubes (CNTs)	The findings of this study proposed that the material containing 2 % exhibits an increases of 20% in hardness and overall material properties.	[77]
8	Al-Cu alloys	ECAP	Φ=120 °	AA2017 + 10% of Al_2O_3 and AA2017 +10% of SiC	Al_2O_3 or SiC were used to produce Metal Matrix Composites MMCs. However, ECAP was an alternative way of enhancing metal properties.	[78]
9	Al/Al_2O_3-TiB_2	vortex casting method + warm ECAP + hot extrusion	Φ = 90° Ψ = 20°	Al_2O_3/TiB_2 20 µm contains 2%.	The researcher fabricated a new MMCs by using vortex casting method. Therefore, the warm ECAP with hot extrusion were performed to enhance the material properties. ECAP and extrusion leads an increase of the relative densities of the material.	[20]

Table 6 chemical composition of commercial glasses [79]

Glasses and uses	SiO2	Al2O3	B2O3	Na2O	K2O	MgO	CaO	BaO	PbO	others
Soda-lime glasses- Containers	66–75	0.7-7		12-16	0.1-3	0.1-5	6-12			
Float	73-74			13.5-15	0.2	3.6-3.8	8.7-8.9			
Sheet	71-73	0.5-1.5		12-15		1.5-3.5	8-10			
Light bulbs	73	1		17		4	5			
Tempered ovenware	75	1.5		14			9.5			
Borosilicate Chemical/apparatus	81	2	13	4						
Pharmaceutical	72	6	11	7	1					
Tungsten sealing	74	1	15	4						
Lead glasses/ Color TV funnel	54	2		4	9				23	
Neon tubing	63	1		8	6				22	
Electronic parts	56	2		4	9				29	
Optical dense flint	32			1	2				65	
Barium glasses Colour TV/panel	65	2		7	9	2	2	2	2	10% SrO
Optical dense barium crown	36	4	10						41	9% ZnO
Alum inosilicate Combustion - tubes	62	17	5	1		7	8			
Fibre-glass	64.5	24.5	5	1		10.5				
Resistor-substrates	57	16	4			7	10	6		

Table 7 Different Types of Wastes Reinforced Light Metal Matrix Composites (MMCs)

No	Reinforced Particles	Metal Matrix Composites (MMCs)	Hardness (HRB/BHN)	Yield Strength (MPa)	Elongation [E] %	Tensile strength (N/mm^2)/MPa	Ref
		Natural Wastes Particles					
1	Breadfruit Seeds Ash	12% Breadfruit Seeds Ash (BSA)/ Al–Si–Fe alloy	85 (HRB)	190 (MPa)	5.7	215 (MPa)	[80]
2	Coconut	• 15 % Al / Coconut	46 (BHN)	-	-	-	[81]
		• 10% Al/ coconut + SiC	44.5 (HV)	-	-	124 (MPa)	[82]
3	Bagasse	• 30 % Al-7 % Si alloy	90.767 (HRV)	-	-	176.683 (MPa)	[50]
		• Aluminium-7075/ Graphite and Bagasse-Ash	99 (BHN)	200.86 (MPa)	4.9	299.4 (MPa)	[49]
4	Rice Husk (RH)	• Al-9 % of RHA	33.60 (BHN)	61.0 (MPa)	-	115.320 (MPa)	[51]
		• Al / 12 % RHA	80 (BHN)	-	7	174.6 (MPa)	[83]
		• Al / 6% RHA	-	-	1.96	356.68 (MPa)	[84]
		• Al7075 / 15%RHA + 10% SiC+10% Phosphor Bronze	97 (BHN)	-	-	97 (MPa)	
5	Wood - ceramic (WC)	• Mg alloy / ZK60A	-	213.3 (MPa)	-	391.8 (MPa)	[53]
		Mg alloy / Wood Ceramics	-	25.6 (MPa)		44.9 (MPa)	
6	Ramie	• Fabric / 3% Cotton-Ramie	-	-	-	65.66 (MPa)	[85]
7	Bamboo	• Al6063 / 10% Bamboo	-	-	-	96 (MPa)	[86]
		• Al / 4% Bamboo	99.3 (BH)	133.19 (MPa)	2.8	177.304 (MPa)	[87]
8	Eggshell	• Al – Cu – Mg / 12% Eggshell	74.17 (HRF)	-	-	112.84 (MPa)	[88]

9	Kenaf	• Polyester / Kenaf • Aramid Woven Kenaf	- -	- -	- -	15.00 (MPa) (145.8) MPa	[89] [55]
		Industrial Wastes Particles					
10	Waste Glasses	• Magnesium Alloy / 6% SiO_2 Glass Scraps	82 (HV)	270 (MPa)	6	330 (MPa)	[90]
11	Electric Arc Furnace Dust (EAFD)	• Aluminium / 10% Arc Furnace Dust •	74 (HV)	-	-	248 (MPa)	[57]
12	Steel Slag	• AA 2024 / 5% Slag • A356 alloy / Steel Slag	120 (VHN) 107 (HV)	- -	- -	300 (MPa) 135 (MPa)	[91] [92]
13	Red Mud	• Aluminium 6061 / 10% Red Mud • Al 7075/ 7.5% Red Mud	22 (HRB) 114.29 (VHN)	- -	- -	190 (MPa) -	[93] [94]
14	Industrial sludge	• Aluminium powder / 2% Alumina Sludge	87.9 (HV)	-	-	-	[95]