

Lateral Compressive Behaviour of Aluminium Matrix Composites by Improved Powder Metallurgy Process

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ABSTRACT: The industrial waste such as fly ash and bagasse ash are most promising alternative reinforcement material for the metal matrix composites. Also alumina reinforcement is used commercially for various automotive applications. The present work is focused on the manufacturing of aluminum matrix composites (AMCs) by powder metallurgy technique. These reinforcement materials are reinforced with pure aluminium in a 5%, 10% and 15% by weight percentage in between that use ethanol as a binder. After preparation of homogeneous mixture compaction is carried out on universal testing machine. The sintering is carried out in muffle furnace at 630⁰ C for the period of 2 hr. The specimens were allowed to cool at normal atmosphere inside the muffle furnace. After complete preparation of specimen by powder metallurgy technique, specimens were tested to identify the lateral compressive strength of the AMCs. It is observed that due to addition of industrial waste in pure aluminium lateral compressive strength of material increases with increase in percentage reinforcement. This study will be useful in material that plays a vital role in the light weight application such as aerospace, automobile and sporting industries.

KEYWORDS: Aluminium Matrix Composites (AMCs), Powder Metallurgy (PM), industrial waste, fly ash (FA), bagasse ash (BA), alumina (Al₂O₃), lateral compressive strength.

I. INTRODUCTION

Aluminium (Al) is the most abundant metal in Earth's crust. Al acquires about 8% by weight of Earth's solid surface. Al is widely used due to its availability, high strength to weight ratio, due to enhanced machinability, durability, ductility and malleability. Further, Aluminium based Metal Matrix composites (MMC) have received increasing attention in recent decades as engineering materials due to their enhanced high strength to weight ratio, good corrosion resistance, enhanced thermal conductivity, better machinability and recyclability. It is mainly recognized for suitable wear resistance application over conventional Al alloy. It is one of the most prospective matrix metals for the production of composites [1, 2].

Aluminium alloys are widely used in various automobile and aerospace industries because of their high strength to weight ratio and modulus. The light weight parts manufactured by using the aluminium matrix composites have led to their use in the automobile and aerospace industries. Aluminium matrix composites have increasing potential due to various applications like brake rotors, cylinder liner, engine parts, pistons, cylinder heads, etc. The production of aluminium composite material by better quality and less expensive materials like industrial waste is the need of technology. The properties of AMCs change considerably due to reinforcement type like fly ash, bagasse ash, alumina, etc. [2, 3].

The present work is focused on the use of industrial waste such as fly ash, bagasse ash and alumina as a commercial reinforcement material. These are most promising alternative reinforcing metal matrix composites. The paper represents a study of different properties of the aluminium matrix composite with fly ash, bagasse ash and alumina powder as reinforcement material in pure aluminium by the route of powder metallurgy technique. Powder metallurgy (PM) is a term covering a wide range of ways in which materials or components are made from metal powders. PM processes can

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avoid, or greatly reduce, the need to use metal removal processes, thereby drastically reducing yield losses in manufacture and often resulting in lower costs. Powder metallurgy is also used to make unique materials impossible to melt or form in other ways.

The materials and methods used for the present work includesash which falls in the bottom of the boiler is called bottom ash. Fly ash is generally captured by electrostatic precipitators or other particle filtration equipment before the flue gases reach the chimneys of coal-fired power generation plants, and together with bottom ash removed from the bottom of the boiler is known as coal ash. Bagasse is a by-product from the sugar industry and it is usually burnt at the mill to provide process power or steam that provides energy for process machineries. The use of sugar cane bagasse as a source of energy, because of its appreciable calorific value, leads to production of ash as waste which has no specific economic application.

II. ALUMINIUM ALLOY

Aluminium alloy used where weight saving is required because of its light weight application and softness aluminium alloy can restrict its use for the engineering applications. Hence, the strengthening of this metal is required for its use in cars, light-weight armour vehicles, rockets, missiles, aircraft, and structures in civil and defence sectors which demand high strength-to-weight ratio. The strengthening of Al is principally done by alloying it with elements like Cu, Zn, Mn, Mg, Si, and Li and processing its alloys [2].

III. ALUMINIUM MATRIX COMPOSITES

Metal matrix composites (MMCs) attract great deals of attentions nowadays due to their great mechanical properties and also their further applications in advanced industries such as automobile and aerospace. Meanwhile, reinforcing of light metals, such as Al, with ceramic particles enhances wide spectrum of properties including yield and tensile strength at room temperature, creep and fatigue resistance at higher temperatures, hardness, compressive strength, and thermal shock resistance. Different types of ceramic particles such as Al_2O_3 , B_4C , and SiC, have been implemented for Al matrix composites [4].

The purpose of developing metal matrix composite materials is to combine the desirable properties of metal and ceramics. The major advantages of aluminium matrix composites compared to unreinforced materials are greater strength, improved stiffness, reduced density, improved temperature properties, controlled thermal expansion and improved wear resistance [5].

Various kind of ceramic materials, e.g. SiC, Al_2O_3 , MgO, B_4C and also industrial waste such as fly ash, bagasse ash are extensively used to reinforce aluminium alloy matrices. Because of that the properties of these materials such as refractoriness, high hardness, high tensile strength, wear resistance etc. make them suitable for use as reinforcement in MMCs [5, 6].

IV. USE OF INDUSTRIAL WASTE AS REINFORCEMENT MATERIAL

In recent past years different matrices or alloys (metal/nonmetal) were reinforced with ceramic particulates gives considerable interest due to their inherent good mechanical as well as tribological properties [6] and low cost. In the present investigation more difficulties occur due to the rapid environmental degradation and high production cost, it stands as a challenge for the industries to compete with others in the market. As implementation of composite forming procedure along with decreases the production cost concurrently enhancing the property of the materials, hence in this article the usability of one of such industrial waste material i.e. fly ash, bagasse ash [6, 7, 8, 9, 10] has been reviewed extensively for both the above said purposes i.e. the need of an alternative eco-friendly solution and the property enhancing ability of the fly ash, bagasse ash.

i.Fly Ash: -Fly ash is waste material produced from thermal power stations. Fly ash is currently used as a waste product for places like land fill as fillers in concrete and other materials [11].Fly ash is one of the residues generated in combustion and there fine particles that used from the flue gases. Ash which does not rise is termed bottom ash. In an

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industrial context, fly ash usually refers to ash produced during combustion of coal. Fly ash is generally captured by electrostatic precipitators or other particle filtration equipment before the flue gases reach the chimneys of coal-fired power plants and together with bottom ash removed from the bottom of the furnace is in this case jointly known as coal ash [5]. Depending upon the source and makeup of the coal being burned, the components of fly ash vary considerably, but all fly ash includes substantial amounts of silicon dioxide (SiO_2) (both amorphous and crystalline) and calcium oxide (CaO), both being endemic ingredients in many coal-bearing rock strata. Generally, fly ash contains the oxides of silicon, iron, titanium and rest of others shown in Table no. 1.

Table 1: The chemical composition of fly ash is shown below (by weight %) [7, 8]

Al_2O_3	SiO_2	Fe_2O_3	TiO_2	LOI
28.44	59.96	8.85	2.75	1.43

ii. Bagasse Ash: -Bagasse is a waste product from the sugar industry and it is usually burnt at the mill to provide process power or steam that provides energy for process machineries. The use of sugar cane bagasse as a source of energy, because of its appreciable calorific value, leads to production of ash as waste which has no specific economic application. A new reuse process of these wastes has to be established because these wastes, their ashes and gases are environmental burdens. Reinforcing aluminium metal with bagasse ash as a source of silica and alumina particulate will yield a material that displays combination of physical and mechanical properties of both the metal matrix and the silica [6, 10]. Generally, bagasse ash contains the oxides of silicon, iron, calcium and rest of others shown in Table no. 2.

Table 2: Chemical Composition of Sugarcane Bagasse Ash (by weight %) [10]

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	Others	LOI
77.29	10.95	3.66	2.09	1.49	0.49	3.16	0.38	Balance	3.28

V. MANUFACTURING PROCESSES

The manufacturing processes are classified according to whether the matrix is in the liquid, solid or vapour phase while it is combined with the reinforcement [12]. In general the most common manufacturing MMC technologies are divided primarily into two main parts: primary and the secondary. The primary processing is the composite production by combining ingredient materials (powdered metal and loose ceramic particles, or molten metal and fiber performs), but not necessarily to final shape or final microstructure and the secondary processing is the step which obviously follows primary processing, and its aim is to alter the shape and microstructure of the material (shape casting, forging, extrusion, heat treatment, machining). Secondary processing can change the constituents (phase, shape) of the composite. So, MMCs can be made by different ways [13].

i. Stir Casting: Stir casting is simple and commercial method is known as ‘vortex technique’ or ‘stir casting technique’ it is attractive because of simplicity, low cost of processing, flexibility, most economical for large sized components to be prepared as well as production of near net shaped components. The vortex technique involves the introduction of pre-treated ceramic particles into the vertex of molten alloy created by the rotating impeller. An interesting recent development in stir casting is a two-step mixing process. In this process, the matrix material is heated to above its liquids temperature so that the metal is totally melted. The melt is then cooled down to a temperature between the liquids and solidus points and kept in a semi-solid state. At this stage, the preheated particles are added and mixed. The slurry is again heated to a fully liquid state and mixed thoroughly. This two-step mixing process has been used in the fabrication of aluminum [4, 13].

ii. Squeeze Casting: Squeeze casting is also known as liquid metal forging is a combination of casting and forging process. The molten metal is poured into the bottom half of the pre-heated die. As the metal starts solidifying, the upper half closes the die and applies pressure during the solidification process. The amount of pressure thus applied is

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significantly less than used in forging, and parts of great detail can be produced. Coring can be used with this process to form holes and recesses. The porosity is low and the mechanical properties are improved. Both ferrous and non-ferrous materials can be produced using this method [13].

iii. Compo-casting: Compo-casting is a liquid state process in which the reinforcement particles are added to a solidifying melt while being vigorously agitated. It has been shown that the primary solid particles already formed in the semi-solid slurry can mechanically entrap the reinforcing particles, prevent their gravity segregation and reduce their agglomeration. These will result in better distribution of the reinforcement particles. The lower porosity observed in the castings has been attributed to the better wettability between the matrix and the reinforcement particles as well as the lower volume shrinkage of the matrix alloy [13].

iv. Powder Metallurgy:-The life cycle of P/M process needs a different sequence of operations with various machines to manufacture the composites which exhibits the various stages like blending, mechanical alloying, compacting, sintering and inspecting the products, involved in powder metallurgy process. In P/M laboratory, the needed metal powders are mixed in different ratios, compressed and sintered to prepare composites of pre-designed forms, which will be used as models to manufacture various products such as aircraft parts, aluminium coins and snowing machinery parts etc. [14]. Powder metallurgy (P/M) can be defined as the art of producing powders of metals, alloys, ceramics etc. mixing them in necessary quantities, compacting and sintering into machine parts. The P/M process is a unique part fabrication method that is highly cost effective in producing simple or complex parts close to final dimensions [15].

Advantages of Powder Metallurgy: [4]

- 1) Better bonding of matrix and particles.
- 2) Better distribution of particles.
- 3) Easier control of matrix Structure.
- 4) The tolerance of components produced by this technique have quite high tolerance, therefore no further machining is not required.
- 5) The technique required no secondary operations.

Limitations of Powder Metallurgy: [4]

- 1) The process has high complexity.
- 2) There may be chances of high portions of porosity in this process.

VI. EXPERIMENTAL PROCEDURE

The present work focuses on the use of industrial waste such as fly ash and bagasse ash as reinforcement materials in pure aluminium at 5%, 10% and 15% by weight percentage as shown in table no.3. This reinforcing material mixed with pure aluminium to prepare homogeneous mixture using ethanol as a binder and compaction is done to get required shape of specimen by powder metallurgy process. The sintering was carried after compacting at 630⁰C. The specimens were kept at 630⁰C at least 2 hr. The specimens were allowed to cool at normal atmosphere. After complete preparation of specimen by powder metallurgy technique, specimens were tested to identify strength. Fig. 2 shows process of P/M.

i. Manufacturing of Die and Punch: Manufacture the Die and Punch from the hard material i.e. EN 8. The dimensions of die with outer dia. 60mm, inner dia. 40mm and height 120 mm. The dimensions of punch are height 250mm and diameter of punch 39.9mm. Following Fig. 1 shows the actual images of die, punch and there assembly

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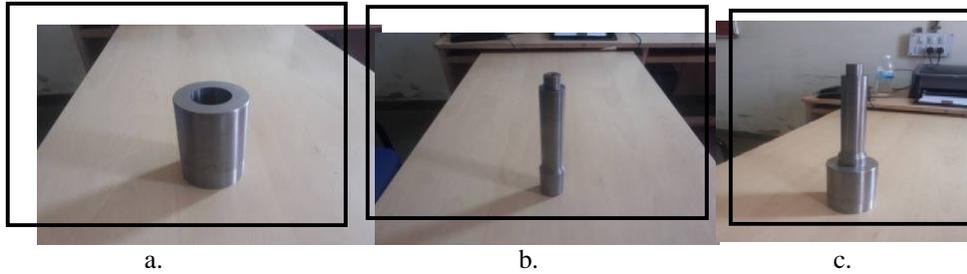


Fig. 1 a) Die, b) Punch, c) Assembly of die and Punch.

ii. Metal or alloy powder: The selection of material and process parameters required extensive literature review [15]. Before using selected powder i.e. aluminium metal powders it necessary to study the micro structural behavior of the metal powder to be selected. Also on the other hand it is necessary to study the reinforcement material properties and there chemical composition. Reinforcement powder was sived by using siveshekar desired range.

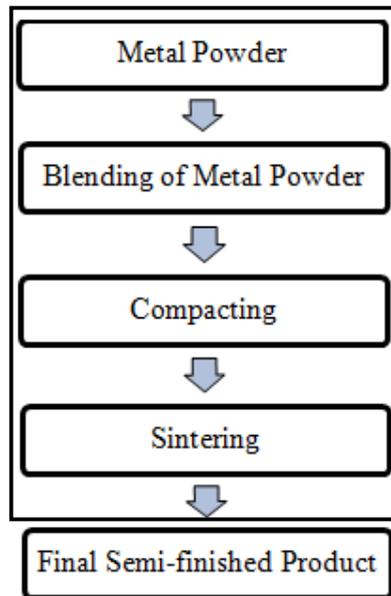


Fig. 2 Powder Metallurgy Process [15]

ii. Blending: The required quantity of metal powders are mixed in different ratios using stirrer to prepare alloy powders in homogeneous form upto 30 min. mixing using the Ethanol as binder between the aluminium metal powder and reinforcement material. The homogeneous mixture can be obtained by using reinforcement material in percentage wise by blending it in proper proportion which is shown in Table 3

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Table3: Mechanical alloying elements in different weight percentage.

Sr. No.	Material	% Reinforcement
1.	Pure Aluminium	100% Al
2.	5% Fly ash	95% Al + 5% FA
3.	10% Fly ash	90% Al + 10% FA
4.	15% Fly ash	85% Al + 15% FA
5.	5% Bagasse Ash	95% Al + 5% BA
6.	10% Bagasse Ash	90% Al + 10% BA
7.	15% Bagasse Ash	85% Al + 15% BA
8.	5% Alumina	95% Al + 5% Al ₂ O ₃
9.	10% Alumina	90% Al + 10% Al ₂ O ₃
10.	15% Alumina	85% Al + 15% Al ₂ O ₃

iii. Die Compacting: The die-punch assembly is used to compress the above powder mixture on the Universal Testing Machine (UTM) to get required specimen shape. Compaction is the first step in the shaping of loose powders into a product of desired form and sufficient strength for further handling. But during compacting of an aluminium metal powder it is necessary to maintain the compacting ratio 2.6 gm/cm³ for aluminium. But, required specimen for lateral compressive strength is of disc like shape with dimensions (dia.40mm x height 10mm). So, maintain that compacting ratio it is necessary to calculate the mass of powder required for compaction.

$$\text{Density} = \text{Mass} / \text{Volume}$$

Let,

Mass (m) = Calculate mass of reinforcing material

Diameter (d) = 4cm

$$\text{Density} = 2.6 \text{ gm/cm}^3 \text{ (Density of Al)}$$

Length (l) = 1.5 cm

Density = $\frac{m}{\pi r^2 l}$

$$2.6 = \frac{m}{\pi (2)^2 1.5}$$

$$m = 49 \text{ gm}$$

It is mostly done by unidirectional compaction on a punch or to a lesser extent by cold isostatic pressing (CIP). In a first stage the particles are rearranged leading to a better packing. Increasing pressure provides better packing and decreasing porosity.

iv. Sintering: When a powder compact is heated in a protective atmosphere to a temperature below the melting point of the major component, a densification of the powder occurs by eliminating pores and a sintered product of increased mechanical strength is formed. On a microscopic scale, cohesion takes place as necks form and grows at the points of particle contact. The sintering temperature is typically in between 600°C to 650°C. Sintering is done by using the muffle furnace as shown in Fig. 3.

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Fig.3 Final Sintered specimen by Powder Metallurgy method

VII. EXPERIMENTAL RESULTS

After complete preparation of specimen by powder metallurgy technique, specimens were tested to identify strength. The lateral compressive testing was carried to study the effect of industrial waste as reinforcement in the pure aluminium.

The table no. 4 gives the reading for the lateral compressive strength of the fly ash, bagasse ash and alumina reinforcement in pure aluminium at different weight percentage. It observed that as the percentage reinforcement of fly ash, bagasse ash and alumina increases the lateral compressive strength also increases

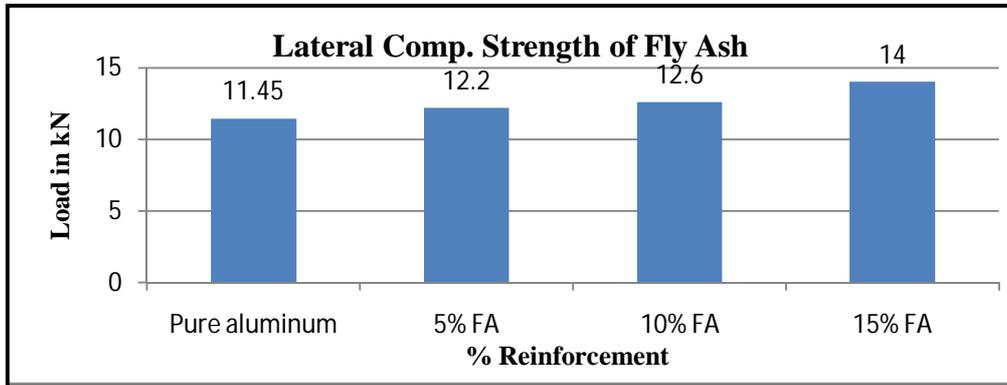
Table4: Readings of Lateral Compression test

Sr. No.	Reinforcement	Lateral Compression (kN)
1.	Pure Aluminium	11.45
2.	Al + 5%FA	12.2
3.	Al + 10%FA	12.6
4.	Al + 15%FA	14
5.	Al + 5%BA	15
6.	Al + 10% BA	20
7.	Al + 15%BA	25
8.	Al + 5% Al ₂ O ₃	16
9.	Al + 10% Al ₂ O ₃	19
10.	Al + 15%Al ₂ O ₃	19.6

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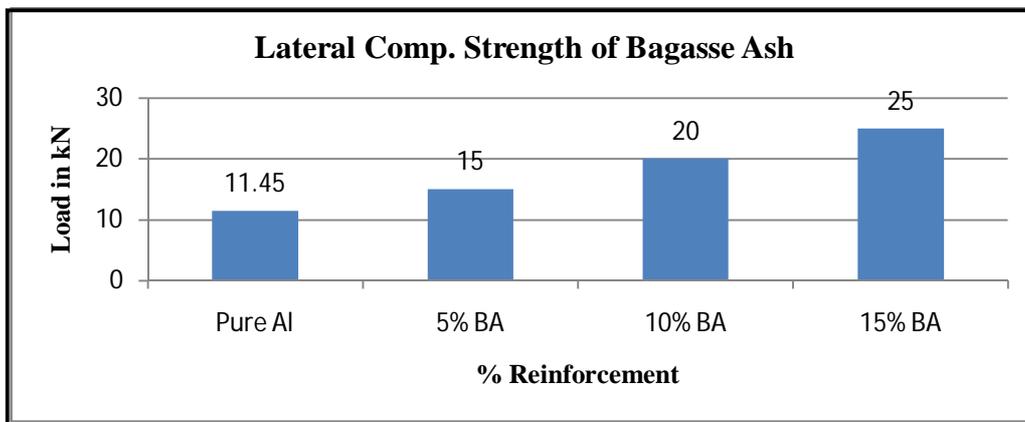
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Graph no. 1 Lateral compressive load (kN) vs. %Reinforcement

The above graph shows that in case of 15% fly ash reinforcement it is found that lateral compressive strength is 18.21% greater than that of the pure aluminium. Also from graph it is observed that as percentage reinforcement increases lateral compressive strength also increases. As shown graph no. 1.



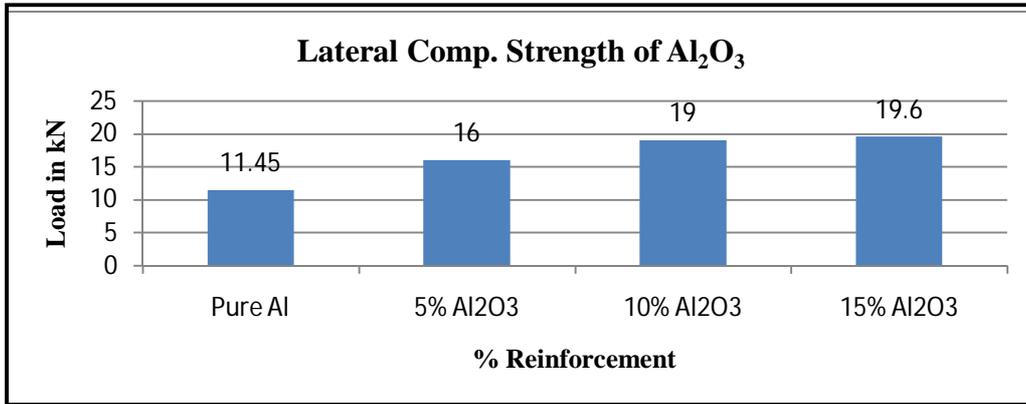
Graph no. 2 Lateral compressive load (kN) vs. %Reinforcement

In case of 15% bagasse ash reinforcement it is observed that lateral compressive strength is 54.2% greater than that of the pure aluminium. Also from graph it is observed that as percentage reinforcement increases lateral compressive strength also increases. As shown in graph no. 2.

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Graph no. 3 Lateral compressive load (kN) vs. %Reinforcement

In case of 15% alumina reinforcement it is found that lateral compressive strength is 41.58% greater than that of the pure aluminium. Also from graph it is observed that as percentage reinforcement increases lateral compressive strength also increases. As shown in graph no. 3.



Graph no.4 shows the all % reinforcement vs. Load in kN

The above graph no. 4 shows the lateral compressive strength of all reinforcement material with pure aluminium shows that as reinforcing percentage of each material increases lateral compressive strength also going to be increases.

VII. CONCLUSIONS

The aluminum matrix composites based specimen was manufactured by using the improved powder metallurgy technique at the different reinforcement percentage as 5%, 10% and 15% to investigate the, lateral compression of the industrial waste as reinforcement material such as fly ash, bagasse ash and alumina in pure aluminium.

The lateral compressive strength of fly ash, bagasse ash and alumina increases with increase in percentage reinforcement than pure aluminium. In case of 15% BA lateral compressive strength is 54.2% than that of pure aluminium. Also in case of 15% alumina and 15% FA lateral compressive strength is 41.58% and 18.21% greater than that of pure aluminium respectively. Therefore the lateral compressive strength are in such a manner bagasse ash>alumina>fly ash> pure Al.

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Therefore work shows that it is possible to manufacture the specimen by using industrial wastes like fly ash, bagasse ash & alumina by successfully reinforcement with the pure aluminium gives the semi-finished product by using powder metallurgy technique with great strength.

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