Aluminium Fly Ash Metal Matrix Composites–A Value added Material made from thermal Power Plant's Waste Disposal

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Abstract—*The industrial challenge is to dispose and reuse waste coming out of them. Many of the thermal power plants are facing to disperse their waste that is the fly ash. The aluminum matrix composites find important applications in the field of automobile and aerospace where high strength and high modulus can be achieved. The byproduct of coal burning in thermal power plants is drawing lot of attention as reinforcement for MMCs due to its low cost and results to help in the reduction of environmental pollution. The fly ash particles are generally hollow in nature and possess lower densities. The oxides in fly ash give high values of modulus and strength thereby improving specific strength and stiffness along with lower densities in relation to many metal based systems. Metal Matrix Composites are used in critical applications due to its low fracture toughness compared to metals. In the present work the results of the influences of weight fraction of fly ash particles on hardness, tensile strength and fracture toughness are evaluated. The hardness of Aluminium fly ash metal matrix composites increased with the addition of particles of fly ash as reinforcement. Results showed the tensile strength and fracture toughness K_{IC} and J_{IC} of the aluminum fly ash particulate composite decrease compared to the base alloy.*

1. INTRODUCTION

The ash coming from thermal power plant after complete Fly ash utilization of the coal burnt for running of the thermal power plant is disposed off outside the power plants in large heaps. Indeed it is becoming a big problem to the thermal power plants in the socio and economic aspects. The ash is creating a large number of diseases. Continuous requests are being faced by the thermal power plants to get the fly ash from the place because of its environmental pollution.

Ash formed after the Volcanic flow acts just like fly ash obtained from coal-fired thermal power plants.

During the last 30 years, very extensive research has been carried out in the utilization of the fly ash in various sectors, as this is not considered as hazardous waste [4,5]. Broadly, fly ash utilization programmes can be advantageous from two angles, i.e. mitigating the environmental effects and addressing the disposal problems by low value–high volume utilization.

Table 1: Showing Thermal power generation, coal consumption and ash generation in India

Year	Thermal power generation in mW	Consumption of Coal in mt	Generation of Ash in mt
2000	70,000	250	90
2010	98,000	300	110
2020	137,000	350	140

2. MECHANICAL UTILIZATION OF FLY ASH AS MELTING AND CASTING:

The aluminum fly ash metal matrix composite was prepared by stir casting method. The casting is done by taking 500gm of commercially pure aluminum and calculated amount of fly ash particles. The sample of fly ash particle after segregating size wise was preheated to 300^0C for three hour to remove moisture left in it. Commercially pure aluminum powder was melted in a resistance furnace. The melt temperature was maintained at 700^0C. A designed mild steel turbine stirrer is used to stir the melt. The stirring was done for 5 to 7 min at an impeller speed of 200 rpm. The melt temperature was set to 700^0C during addition of fly ash particles. The dispersion of fly ash particles were progressed by the vortex method. Both the particulate and pure Aluminum were allowed to mix up thoroughly and uniformly stirred. The molten melt was poured into the preheated mold. The pouring temperature of the molten mixture was maintained at 680^0C. The melt was then cooled to solidify the moulds for some time. Different specimens were made with a different Weight percents of fly-ash (i.e.5, 10, 20, wt %).

Table 2 showing the % Composition of Fly Ash

S. No.	Name of the Compound	% Composition
1.	Si O2	67.2

2.	Al2O3	29.6
3.	Mg O	1.7
4.	Ca O	1.4
5.	Fe2O3	0.1

Metal Matrix composites are cost and low fracture tough than the commercial alloys. But the Aluminum Metal Matrix composites emerge as important materials because of high specific strength and stiffness as well as other desirable properties. The Aluminium alloy matrix composites are extensively being used for high performance applications in automobile and aerospace. Because there are so many advantages, efforts are being made continuously to process Aluminum ceramic reinforced metal matrix composites with low cost reinforcement. Fly ash which is by product of coal burning is drawing lot of attention as reinforcement for MMCs due to its low cost and reduction in environmental pollution. The fly ash particles, generally being hollow in nature, display lower densities while oxides present as constituents make them possess high modulus and strength thereby enhancing specific strength and stiffness along with lower densities compared to many metal based systems. The measurement of valid plane strain fracture toughness, (K_{IC}) and Elastic plastic fracture toughness (J_{IC}) for Aluminum Matrix particulate reinforced metal matrix composites is an important step in the process of developing useful products from these materials and increasing confidence in their properties and performance. However limited work has been reported in open literature on the influence of fly ash on fracture toughness of aluminum metal matrix composites.

The value of the K_{IC} and J_{IC} characterizes the fracture resistance of a material in the presence of a sharp crack under tensile loading, where the state of stress near the crack front is a triaxial plane strain, and the crack-tip plastic region is small compared with the crack size and specimen dimensions [3-6]. In 1977 Barker [7] proposed the short-rod specimen for determining plane strain fracture toughness. Waszczak [8] investigated the applicability of LEFM (K_{IC}) to Boron /Aluminium composites and reported the non linear behavior of load vs COD (crack mouth Opening displacement) curve due to large scale plasticity of AA6061 aluminium alloy.

The LEFM method of fracture toughness of Al/SiC metal matrix composites were studied by few researches [9-11] and reported that the fracture toughness of the Metal Matrix Composites depends on the volume fraction and aspect ratio of the particles. Hong et al. [11] showed that the fracture toughness of SiO_2/Pure Al composite decreases from 20.16 MPa $m^{1/2}$ to 14.67 MPa $m^{1/2}$ when the volume fraction of the SiO_2 particles increases from 3% to 10%. Hasson and Crowe [12] showed that the K_{IC} value is 15.8 $MPam^{1/2}$ for a 25 vol.% SiC_p reinforced 6061 Aluminum alloy composite in T6 condition, while the value is only 7.1 $MPam^{1/2}$ for a 20 vol.% SiC_w reinforced 6061 Al alloy composite in T6 condition. The uses of MMCs are thus impeded in critical applications. LEFM (Linear Elastic Fracture Mechanics) has been used by researchers to characterize the plane strain fracture toughness using various specimen geometries and notches. [13–23]. However there were very few studies using EPFM (Elastic Plastic Fracture Toughness) are reported in open literature.

Table 3: Showing the details of various Thermal Power Plants in India under the name of NTPC

Name of the Thermal Power Station	Location	District	State	Capacity in mW
Badarpur Thermal Power Plant	Badarpur	New Delhi	NCT Delhi	705
Singrauli thermal Power Plant	Shaktinagar	sonebhadra	Uttar Pradesh	2000
Rihand Thermal Power Plant	Rihand nagar	sonebhadra	Uttar Pradesh	2000
Feroz Gandhi Unchahar	Unchahar	Raebareli	Uttar Pradesh	1050
Thanda Thermal Power Plant	Vidyutnagar	Ambedkarnagar	Uttar Pradesh	440
Korba Super Thermal Power Plant	Jamani Palli	Korba	Chattisgarh	2100
Sipat Thermal Power Plant	Sipat	Bilaspur	Chattisgarh	1000
Vidhyachal Super Thermal Power Station	Vidhya nagar	Siddi	Uttar Pradesh	3260
Ramagundam Super Thermal Power Station	Jyothi nagar	Karimnagar	Andhra Pradesh	2600
Simhadri Super Thermal Power Station	Simhadri	Visakhapatnam	Andhra Pradesh	1000
Farakka Super Thermal Power Station	Nagarun	Mushidabad	West Bengal	1600
Kahalgaon Super Thermal Power Station	Kahalgaon	Bhagalpur	Bihar	2340
Talcher Super Thermal Power Station	Kaniha	Angul	Odisha	3000
Talcher Thermal Power Plant	Talcher	Angul	odisha	460

In the following given data as per Table 3, the Simhadri Thermal Power Plant, Visakhapatnam is producing 1000 mW of energy. The industrial fly ash is to be disposed for environmental as well health consideration. Not only to dispose the industrial waste it is very necessary to give value addition to such industrial waste. Studies have been done towards this idea and this proposal is done to give value addition to industrial waste. The metals present in the fly ash are given in the table 2.

The details of % composition of the fly ash, reinforcement size, pre heat temperature, time taken for stirring, pouring temperature of the specimen manufacturing is given in the table 4.

Table 4: Showing the Stir casting process details for fabrication of Aluminum fly ash composition

S. No.	Reinforcement Particulate size of the fly ash	% composition	Preheat temperature(0C)	Time taken for stirring	Pouring Temp (0C)
1.	About 30 µm	5	750	40 Min	725
2.	30-40 µm	10	750	45 Min	725
3.	About 30 µm	15	750	45 Min	725
4.	Approx 30 µm	20	750	45 Min	725

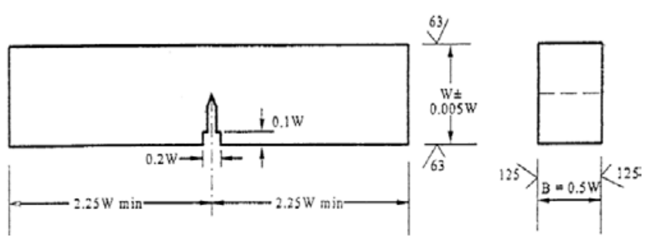
The details of the % Composition of Aluminum 6061 taken as the matrix material for the experimentation is given in the table 5. stir casting technique is adopted for the manufaturing of the specimen. Dies with the proper allowance are manufactured by using Computer Aided Machine with high accuracy of dimensions.

Table 5: Showing the % Composition of Aluminum 6061.

Component	Amount (wt.%)
Aluminium	Balance
Magnesium	0.8-1.2
Silicon	0.4 – 0.8
Iron	Max. 0.7
Copper	0.15-0.40
Zinc	Max. 0.25
Titanium	Max. 0.15
Manganese	Max. 0.15
Chromium	0.04-0.35
Others	0.05

3. SPECIMEN PREPARATION

Stir casting technique is adopted for the specimen preparation. The specimen is prepared under the presence of inert gas Argon, to avoid oxidation of the particulate components. Various % as shown in the table are manufactured and the results are tabulated. The specimens are manufactured as per the ASME Standards.



4. TEST RESULTS

At the true stress and strain distributions there are 3 general regions

1. Very nearer to the crack tip, there will be a process zone, where the material suffers by irreversible damage.
2. Away from the crack tip, there is a region by linear elastic asymptotic crack tip field, known as the `region of *K* dominance'
3. A very Far from the crack tip the stress field depends on the geometry of the solid and boundary conditions of the specimen.

Experimentally, it is found that this approach works very well under the assumptions inherent in linear elastic fracture mechanics are satisfied.

Careful tests have established the following conditions for the applicability of linear elastic fracture mechanics.

1. All characteristic specimen dimensions must exceed 25 times the expected plastic zone size at the crack tip;
2. For plane strain conditions at the crack tip the specimen thickness must exceed at least the plastic zone size.

For a material with yield stress *Y* loaded in Mode I with stress intensity factor K_I the plastic zone size can be estimated as

$$r_p \sim 2.5 (K_I/Y)^2$$

Where Y is the Yield stress and K_I is Stress Intensity factor

Experiment of linear elastic fracture mechanics to Aluminum Matrix Composite Material

LEFM in a design application requires the following

1. Design and manufacture the laboratory specimen that can induce a prescribed stress intensity factor at the crack tip
2. Calculate the critical stress intensity factors that cause fracture in the laboratory specimen.
3. Calibrate the anticipated size and location of cracks in your structure or component
4. Calculate the stress intensity factors for the cracks in the manufactured specimens under increased loading conditions

The stress intensity factors are easily computed to be

$$\rho_1 = \frac{1}{2}\left(\sqrt{(a+r)^2 + z^2} - \sqrt{(a-r)^2 + z^2} \right)$$

$$\rho_2 = \frac{1}{2}\left(\sqrt{(a+r)^2 + z^2} + \sqrt{(a-r)^2 + z^2} \right)$$

The displacement of the upper crack face can be found by setting r<a and z=0 in these expressions, which gives

$$u_Z = \frac{4(1-\nu^2)\sigma}{\pi E}\sqrt{a^2 - r^2}$$

The stress intensity factor can be found directly from the displacement of the crack faces. The asymptotic formulas show that

$$K_I = \lim_{r \to a} \frac{E u_z(r)}{4(1-\nu^2)}\sqrt{\frac{2\pi}{(a-r)}}$$

which shows that $K_I = 2\sigma\sqrt{a/\pi}$

Vast numbers of crack propagations are calculated to find stress intensity factors in various geometries of interest.

The results of the experimentation are as shown in the table. The fracture toughness for various % composition is tabulated after conducting the experiment for 4 specimens of each % composition and the average value of the test results is taken into consideration. All the cases of tests results the same values in the tens place but vary slightly in the hundredths place. Hence the results obtained were found satisfactory and correct ones.

The displacement and stress near the crack tip can be characterized by three numbers K_I, K_{II}, K_{III}, known as *stress intensity factors*. By definition

$$K_I = \lim_{r \to 0}\sqrt{2\pi r}\,\sigma_{22} \qquad K_{II} = \lim_{r \to 0}\sqrt{2\pi r}\,\sigma_{12} \qquad K_{III} = \lim_{r \to 0}\sqrt{2\pi r}\,\sigma_{32}$$

The stress field near the crack tip is

$$\sigma_{rr} = \frac{K_I}{\sqrt{2\pi r}}\left(\frac{5}{4}\cos\frac{\theta}{2} - \frac{1}{4}\cos\frac{3\theta}{2}\right) + \frac{K_{II}}{\sqrt{2\pi r}}\left(-\frac{5}{4}\sin\frac{\theta}{2} + \frac{3}{4}\sin\frac{3\theta}{2}\right)$$

$$\sigma_{\theta\theta} = \frac{K_I}{\sqrt{2\pi r}}\left(\frac{3}{4}\cos\frac{\theta}{2} + \frac{1}{4}\cos\frac{3\theta}{2}\right) - \frac{K_{II}}{\sqrt{2\pi r}}\left(\frac{3}{4}\sin\frac{\theta}{2} + \frac{3}{4}\sin\frac{3\theta}{2}\right)$$

$$\sigma_{r\theta} = \frac{K_I}{\sqrt{2\pi r}}\left(\frac{1}{4}\sin\frac{\theta}{2} + \frac{1}{4}\sin\frac{3\theta}{2}\right) + \frac{K_{II}}{\sqrt{2\pi r}}\left(\frac{1}{4}\cos\frac{\theta}{2} + \frac{3}{4}\cos\frac{3\theta}{2}\right)$$

$$\sigma_{rr} = \frac{K_I}{\sqrt{2\pi r}}\left(\frac{5}{4}\cos\frac{\theta}{2} - \frac{1}{4}\cos\frac{3\theta}{2}\right) + \frac{K_{II}}{\sqrt{2\pi r}}\left(-\frac{5}{4}\sin\frac{\theta}{2} + \frac{3}{4}\sin\frac{3\theta}{2}\right)$$

$$\sigma_{\theta\theta} = \frac{K_I}{\sqrt{2\pi r}}\left(\frac{3}{4}\cos\frac{\theta}{2} + \frac{1}{4}\cos\frac{3\theta}{2}\right) - \frac{K_{II}}{\sqrt{2\pi r}}\left(\frac{3}{4}\sin\frac{\theta}{2} + \frac{3}{4}\sin\frac{3\theta}{2}\right)$$

$$\sigma_{r\theta} = \frac{K_I}{\sqrt{2\pi r}}\left(\frac{1}{4}\sin\frac{\theta}{2} + \frac{1}{4}\sin\frac{3\theta}{2}\right) + \frac{K_{II}}{\sqrt{2\pi r}}\left(\frac{1}{4}\cos\frac{\theta}{2} + \frac{3}{4}\cos\frac{3\theta}{2}\right)$$

Equivalent expressions in rectangular coordinates are

$$\sigma_{11} = \frac{K_I}{\sqrt{2\pi r}}\cos\frac{\theta}{2}\left(1 - \sin\frac{\theta}{2}\sin\frac{3\theta}{2}\right) - \frac{K_{II}}{\sqrt{2\pi r}}\sin\frac{\theta}{2}\left(2 + \cos\frac{\theta}{2}\cos\frac{3\theta}{2}\right)$$

$$\sigma_{22} = \frac{K_I}{\sqrt{2\pi r}}\cos\frac{\theta}{2}\left(1 + \sin\frac{\theta}{2}\sin\frac{3\theta}{2}\right) + \frac{K_{II}}{\sqrt{2\pi r}}\cos\frac{\theta}{2}\sin\frac{\theta}{2}\cos\frac{3\theta}{2}$$

$$\sigma_{12} = \frac{K_I}{\sqrt{2\pi r}}\cos\frac{\theta}{2}\sin\frac{\theta}{2}\cos\frac{3\theta}{2} + \frac{K_{II}}{\sqrt{2\pi r}}\cos\frac{\theta}{2}\left(1 - \sin\frac{\theta}{2}\sin\frac{3\theta}{2}\right)$$

$$\sigma_{31} = -\frac{K_{III}}{\sqrt{2\pi r}}\sin\theta/2 \qquad \sigma_{32} = \frac{K_{III}}{\sqrt{2\pi r}}\cos\theta/2$$

while the displacements can be calculated by integrating the strains, with the result

$$u_1 = \frac{K_I}{\mu}\sqrt{\frac{r}{2\pi}}\left[1 - 2\nu + \sin^2\frac{\theta}{2}\right]\cos\frac{\theta}{2} + \frac{K_{II}}{\mu}\sqrt{\frac{r}{2\pi}}\left[2 - 2\nu + \cos^2\frac{\theta}{2}\right]\sin\frac{\theta}{2}$$

$$u_2 = \frac{K_I}{\mu}\sqrt{\frac{r}{2\pi}}\left[2 - 2\nu - \cos^2\frac{\theta}{2}\right]\sin\frac{\theta}{2} + \frac{K_{II}}{\mu}\sqrt{\frac{r}{2\pi}}\left[-1 + 2\nu + \sin^2\frac{\theta}{2}\right]\cos\frac{\theta}{2}$$

$$u_3 = \frac{K_{III}}{\mu}\sqrt{\frac{2r}{\pi}}\sin\theta/2$$

5. SUMMARY

1. Uniform distribution of fly ash particles in the aluminum matrix was obtained by liquid metallurgy route of stir casting.
2. The yield strength, Tensile strength and % elongation of Aluminum fly ash metal matrix composites decreases with the increase in reinforcement.
3. The fracture toughness K_{IC} of Aluminum fly ash composite is 16 - 19 MPa$\sqrt{mm}$ as compared to 21 MPa$\sqrt{mm}$ for unreinforced base alloy.
4. The Elastic plastic fracture toughness J_{IC} of Aluminum fly ash composites varied between 5 - 14 KJ/m² as compared to 25 KJ/m² for the base alloy which is similar with the reported data.

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