Attrition index – a measure for environmental pollution caused by alumina

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ABSTRACT: *Aluminium is a bluish or silvery white chemical element from the boron group. In the aluminium industry, the quality of alumina, aluminium ore are commonly assessed on the basis of an important parameter called attrition index (Yang, 2003). Attrition index indicates / signifies chipping affinity of minerals under impact. The attrition index attempts to quantify the tendency of the alumina to break down during handling and produce fines. Alumina particle with a poor attrition index produces more dust, leading to loss of product and environmental pollution during handling and leads to problems in alumina smelters.*

Attrition property of a particle depends upon its physical, mechanical, metallurgical and chemical properties. Attrition is affected by many variables like size, shape, surface, porosity, hardness, cracks, time, velocity, pressure, shear, temperature, etc.

Strength of alumina is currently measured using so called Forsythe technique. Forsythe technique involves producing a fluidized column of alumina in a standardized arrangement and measuring the change in the mass of particles <45 fl m over a set period of time.

In this paper an attempt has been made to evaluate the strength of alumina based on single impact using the newly designed and built experimental rig at CQUniversity Australia. The set-up developed at CQUniversity was based on the approach used by Ghadiri and Bentham et al to evaluate the strength of paracetamol. This method used a glass tube to funnel particles towards a target for a single impact event. Once the particles leave the target material, they are collected on filter paper and sized. The particles are driven by a vacuum behind the filter (Audet & Clegg, 2008).

This paper proposes to extend the work further and develop a more fundamental understanding of alumina particle breakage during single impact.

The output of the research works would be helpful for alumina refineries/industries as well as for environmental agencies to understand more accurately the pollution levels caused by the refineries.

Keywords: Alumina, Attrition index, dust particle, Environmental pollution, Pollution assessment, single impact

Introduction and Background

Aluminium is a bluish or silvery white chemical element from the boron group. After oxygen 47%, silicon 28%, it is the third most teeming element in the nature, accounting for nearly 8% of the Earth crust. Virtually, aluminium is found in all most all food, air and water, soils and clays, in minerals and rocks- but not as a metal. As the alumina has strong affinity to oxygen, naturally it is not found in its free or metallic state. Instead, aluminium is always found chemically combined with other elements particularly oxygen and silicon. Bauxite, a clay-like substance is the principal ore of aluminium (Seymour G. Epstein 1990). It consists largely of the minerals gibbsite $Al(OH)_3$, boehmite γ-AlO(OH), and diaspore α-AlO(OH), together with the iron oxides goethite FeO(OH)), and hematite (Fe2O3), the clay mineral kaolinite($Al_2Si_2O_5(OH)_4$)and small amounts of anatase TiO_2.(Bauxite- Wikipedia).

Because of non ferrous but most widely utilized metal, aluminium can enter the human body by intravenous infusions system or by mouth or by the polluted environment. People may be exposed to high levels of alumina when they eat foods or drink fluids containing high levels of aluminium. Not only that, people may also be exposed to high levels of alumina from the dusty living environments, at the workplace surrounded by the contaminated air, or when receiving the vaccination which is containing aluminium in their formula.

Although aluminium is not normally harmful or inherently toxic, but high levels of aluminium in the human body could cause serious health problems. People can become ill who work around extremely high levels of alumina, especially if the element is inhaled on a daily basis. Some studies have shown that people could experience contact dermatitis when handling aluminium products like antacids, antiperspirants and pots.

Due to the presence of aluminium in air, food and water supply, most of the people suffer from some degree of aluminium toxicity. Aluminium can become poisonous having accumulated exposure and storage in the body by the years and years. That has a range of health effects from skeletal deformities to brain degeneration. Having aluminium in the body people may suffer from weakness, muscle aches, bone pain, Speech problems, premature osteoporosis, and so one.

Particularly aluminium is dangerous to the nervous system, such as mental confusion, headaches, memory loss, nervousness, heartburn, disturb sleep, emotional instability and so one. High levels of aluminium in the body can obstruct the body's ability to digest and use up fluoride, phosphorus and calcium, which prevents bone growth and reduces bone density. High amount of aluminium in the body forces calcium out of the bones, which results in weakness, bone deformation and crippling effects [4].

It is very much essential to keep the environment aluminium dust free as much as possible. Therefore, it is needed to take care when handling the aluminium or aluminium base products or at the time of production of those products. If we know the attrition index of those products then it will be easier how to handle the products, what will be the transport medium, how it will be carried out. Because, when the products transport from one place to another place they impact each other at the same time they impact with the container / transport medium too. If the attrition index of the materials is high, it will be taken a great care to handle the material to produce the less dust, to keep the environment free from pollution.

Literature study

Attrition is a mechanical property of brittle material (such as aluminium, coal, salt, stone, sand & stone etc.) defining chipping of those materials while these are impacted on a hard surface. Index of attrition may be defined as the ratio of volume of the material before impact and various sizes of chips obtained after impact. Attrition of a particle depends upon its physical as well as its mechanical and chemical properties. The "physical properties" of a material include density, electrical resistivity and various thermal properties (in particular, the thermal conductivity). The mechanical properties of a material describe its response to applied loads. For many applications, the ability to support a load, or withstand an impact, without excessive deflection or failure is essential. Mechanical properties are therefore often a critical factor in materials selection (Mcleod & Paterson 2002). Density is an important parameter for aluminum - very many applications take advantage of its combination of good mechanical, thermal or electrical performance at low weight e.g. in transport. Alumina has a good thermal and electrical conductivity, and is cheaper and/or lighter than competing metals such as copper, gold and silver (Ghadiri & Zhang 2002).

Since a theoretical or numerical analysis of comminution or attrition processes, that could be applied to practical design is very difficult, it is common to evaluate the strength of particles and their failure (breakage and chipping) by measuring various indices of friability in a variety of standard systems. Many different types of tests have been described by the British Materials Handling Board (Livk & Ilievski 2007). and in studies such as those by Bemrose and Bridgwater and Kalman, to assess the breakage and attrition tendency of particulate materials. Impact tests are common and aim to subject materials to forces that are similar to those which they would encounter during handling (dilute phase pneumatic conveying, chutes, etc.) and during comminution in jet mills, impact mills, rotating drums, etc. It is believed that by performing tests on either single or groups of particles that collide with walls or with other particles, a representative measure of particle friability can be obtained. Therefore, much effort has been devoted to improving test rigs and measuring systems. Keeping in mind that the main purpose of single particle comminution tests is to understand and describe material behaviour by qualitative figures. Because attrition index of brittle material is largely affected by impact force implied and the hard surface quality on which the grain is impacted.

An alumina is considered as a strong alumina if its attrition index is less than 15 %. All most in all alumina industry, Forsythe's attrition test is normally used to qualify the strength of metallurgical alumina. Most of the research works published have been carried out to identify the calcinations factors that influence fragility of particles. At the same time it is acknowledged that alumina's attrition resistance is correlated with hydrate strength. Therefore a lot of works have been done in view to get the precipitation parameters responsible for strength of hydrate. In some publications, it is highlighted that most alumina samples giving the best attrition index results tend to be coarse. Particle size distribution seems to have an influence on attrition index response (Clerin & Laurent 2001).

Theoretical development

Attrition may be affected by many variables. It is affecting not only the properties of particle like size, shape, surface, porosity, hardness or cracks but also the properties of environment such as time, velocity, pressure, shear and temperature (Bemrose & Bridgwater 1987).

It may be envisaged that there are some co-relation with the attrition index of alumina with the physio-mechanical properties of alumina and this co-relation could be expressed in the following functional form;

$A = f(v, h, t, p, H, \rho, c, \ldots\ldots\ldots\ldots)$

Where,

A = Attrition index

v = velocity of particle

h = distance or height of the fallen particle

t = time to impact with target

p = pressure

H = hardness of impact surface

ρ = material density

c = molecular bonding (crystallization)

The system developed at CQUniversity was based on the approach used by Ghadiri and others (Bentham, Kwan, Boerefinj & Ghadiri 2004) to evaluate the strength of paracetamol powder. The advantages of this process are that a large proportion of the particles in the sample receive a similar impact event. The breakage behaviour obtained should then be able to be related to relatively uniform treatment of the particles. The testing procedure should also require much less material and be carried out over a shorter period of time than for the Forsythe technique. The technique offers the possibility of providing a simple, rapid testing technique for determining alumina strength that ultimately could replace the Forsythe technique, which is currently used.

At present, the technique has been used for determining the breakage characteristics of paracetamol and washed lactose. These particles are relatively weaker than alumina. Ghadiri & Zhang (2002) defined the fractional mass loss per impact as,

$$R_i = \frac{M_o - M_m}{M_o} \tag{1}$$

Where M_o is the original mass of the material and M_m was the mass of material of the same size fraction surviving after impact. In previous studies, Ghadiri & Zhang (2002) showed that for semi-brittle materials, the particulate attrition propensity, R_i, can be related to particle velocity u_p, particle size, l, density, ρ, hardness, H and fracture toughness, K_c, by

$$R_i = \alpha \frac{\rho H l u_p^2}{K_c^2} \tag{2}$$

Where, α is a constant. In reality, it is found that

$$R_i \propto u_p^m \tag{3}$$

In their study, Bentham et al. found that m was between 1.9 and 2.3 and R_i values of between 0.1 and 10%. Although Paracetamol and alumina have significantly different material properties it was found that the value $\beta = \frac{\rho H l}{K_c^2}$ was similar for both materials. Hence the CQUniversity device was designed along similar parameters (Audet & Clegg, 2008).

Objective of the research

The aim of the research is to extend the work previously carried out by Audet and Clegg (2008) on breakage using a single impact device and to extend the work to develop a better understanding of breakage of alumina. The project will be put in the context of existing breakage models, such as those developed by Livk and Ilievski (2007), who developed comprehensive breakage models of alumina using the Forsythe method and Ghadiri and Zhang (2002). Therefore we can easily measure / understand how much aluminium dust will produce during the transportation or in side the factories during its modification/production that will pollute the environment.

Experimental methodology

The system developed at CQUniversity was based on the approach used by Ghadiri and Bentham et al to evaluate the strength of paracetamol. The experiment divides into three steps;

- Collecting the raw sample and measure its size by the Mastersizer.
- Impact the raw sample on the powder breakage rig (Attrition test rig).
- Collecting the final sample from the filter of powder breakage rig and measure the sizes by the Malvern Mastersizer.

The apparatus for attrition rate experiment used is called powder breakage rig (Figure 1) which was developed by Bentham et al. It consist of two parts, one is called "spinning riffler" (Rotary Micro Riffler) and the other is experimental rig. The riffler consists of a vibrating hopper which vibrates the sample down a chute. There is a knob to control the vibration which allows the particle to separate out and travel down the chute as per the requirement velocity of the particles. At the end of the chute the particles are falling on a funnel that has a vortex type orifice which collects the sample evenly and travels down using a glass tube to funnel particles towards a target for a single impact event. The particles are driven by a vacuum behind the filter. At this stage the particle velocity depends upon the pressure difference between vacuum chamber and the lower part of the vacuum chamber which is called differential pressure of the vacuum chamber. Once the particles leave the target, they are collected on filter paper and sized. After the test complete, remove the bottom of the device and then remove the attrited alumina from the filter paper. When the attrited alumina is collected after then it is tested using a Mastersizer to determine the particle size distribution. It is obvious that particle breakage depend on the air stream velocity as well as the distance, particle feed rate, impact material etc.

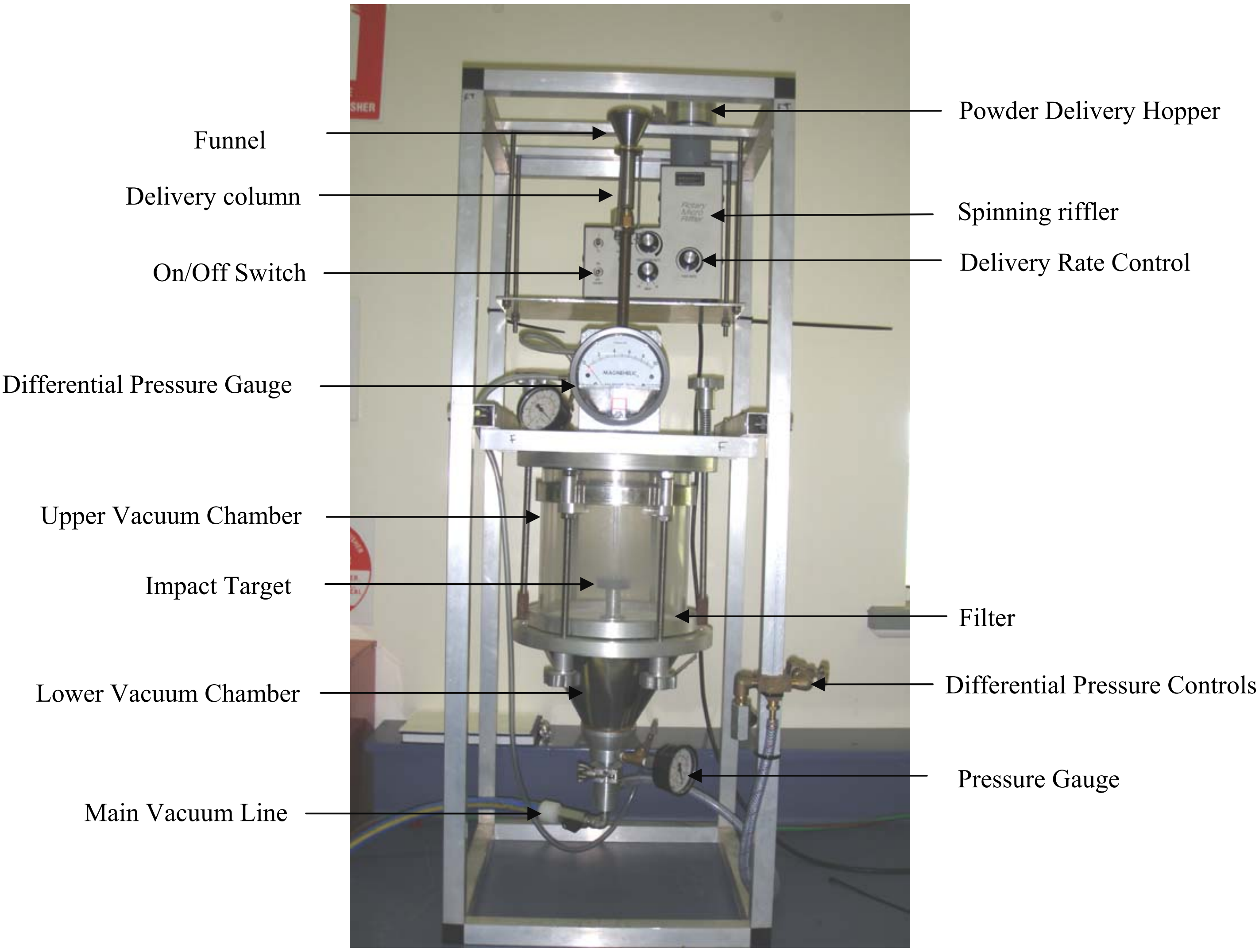

Figure: 1 Powder Breakage Rig

The raw particles are impacted on a target and collected on the filter. Removing the bottom part of the powder breakage rig, the filter is taken out carefully from the vacuum chamber. Collect the attrituted aluminium in suitable bowl and then a small pot or container and marked. The apparatus for measuring or calculating the size% by volume of particle is called Mastersizer (a laser device that can to produce a histogram of particle size distribution). Mastersizer may be of two types called Mastersizer S, Mastersizer X. Mastersizer S is a particle size measurement instrument, controlled and operated from a computer. The particles are presented in suitable medium within a test cell through which a laser beam is focused. The diffraction pattern produced by the particles is measured and from the result the size of the particles is calculated.

Before start the experiment we need to clean up the test cell with clean water. When test cell is cleaned up the water of the beaker change with new and clean water to use as a background for analyse the sample and observe the obscuration figure. When we dissolve the sample slowly with the water the obscuration figure will start to change. We dissolve the sample up to 15%-20% and then start to analyse.

Figure: 2 Malvern Mastersizer

The optical unit is used to collect the raw data, the information from the scattered light when a laser is passed through the sample that is used to measure the size of a sample. The sample preparation accessories is used to prepare the sample and then delivered it to the optical unit via the pipes randomly (a delivery pipe and a return pipe) so that it can be measured. The computer system is an individual computer that runs the Malvern software. It is Malvern software that analyses the raw data from the optical unit to give the size of the particles.

Experimental results and analysis

Three types of aluminium were taken for the experiment. These were supplied anonymously and are labelled RS1 (raw sample), RS2 and RS3.We measured their size one by one with the Malvern Mastersizer and we recorded the results as Y1, Y2 and Y3 in a tabular form and then in graphical form. All three samples had been tested using conventional technique based on attrition index experiment rig. Impacting all the samples one after another and collect them into another three container and are labelled FS1 (final sample), FS2 and FS3. Then again we go for the experiment with the Malvern Mastersizer to measure the new size distribution and the results were distinct as Y4, Y5 and Y6.

As it can be seen in Figures 3 and 4 before impact, all samples showed similar particle size distribution, though the size fraction of sampleY3 is less than other two series. From figure 5 and 6 after impact, samples Y5 and Y7 showed very similar particle size distribution, whereas sample Y4 had a larger particle size with less size fraction.

Table 1 size distribution before and after impact of four types of aluminium sample

Test#>>	Y1	Y2	Y3	Y4	Y5	Y6
Sizes	RS1	RS2	RS3	FS1	FS2	FS3
0.0582	0	0	0	0	0	0
0.0679	0	0	0	0	0	0
0.0791	0	0	0	0	0	0
0.0921	0	0	0	0	0	0
0.1073	0	0	0	0	0	0
0.125	0	0	0	0	0	0
0.1456	0	0	0	0	0	0

0.1697	0	0	0	0	0	0
0.1977	0	0	0	0	0	0
0.2303	0	0	0	0	0	0
0.2683	0	0	0	0	0	0
0.3125	0	0	0	0	0	0
0.3641	0	0	0	0	0	0
0.4242	0	0	0	0	0	0
0.4941	0	0	0	0	0	0
0.5757	0	0	0	0	0	0
0.6707	0	0	0	0	0	0
0.7813	0	0	0	0	0	0
0.9103	0	0	0	0	0	0
1.0604	0	0	0	0	0	0
1.2354	0	0	0	0	0	0
1.4393	0	0	0	0	0	0
1.6767	0	0	0	0	0	0
1.9534	0	0	0	0	0	0
2.2757	0	0	0	0	0	0
2.6512	0	0	0	0	0.26241	0.26241
3.0887	0	0	0.09661	0.09661	0.24536	0.24536
3.5983	0	0	0.08381	0.08381	0.24511	0.24511
4.192	0	0	0.08638	0.08638	0.26189	0.26189
4.8837	0	0	0.1004	0.1004	0.28384	0.28384
5.6895	0	0	0.12447	0.12447	0.30781	0.30781
6.6283	0	0	0.15107	0.15107	0.3163	0.3163
7.7219	0	0	0.17824	0.17824	0.31144	0.31144
8.996	0	0	0.20399	0.20399	0.30682	0.30682
10.4804	0	0	0.21524	0.21524	0.31217	0.31217
12.2096	0	0	0.22172	0.22172	0.37942	0.37942
14.2242	0	0	0.22917	0.22917	0.56073	0.56073
16.5712	0	0	0.26548	0.26548	0.94183	0.94183
19.3055	0.07808	0.07808	0.3742	0.3742	1.62544	1.62544
22.4909	0.1599	0.1599	0.61925	0.61925	2.71226	2.71226
26.2019	0.41304	0.41304	1.08664	1.08664	4.27111	4.27111
30.5252	0.95696	0.95696	1.87783	1.87783	6.28507	6.28507
35.5618	1.9503	1.9503	3.09681	3.09681	8.59092	8.59092
41.4295	3.6044	3.6044	4.79963	4.79963	10.85649	10.85649
48.2654	6.11624	6.11624	6.91508	6.91508	12.72918	12.72918
56.2292	9.20803	9.20803	9.13209	9.13209	13.99246	13.99246
65.507	12.65987	12.65987	11.20095	11.20095	12.33216	12.33216
76.3157	15.47833	15.47833	12.72791	12.72791	9.40574	9.40574
88.9077	16.96538	16.96538	13.62007	13.62007	6.17297	6.17297
103.5775	14.04947	14.04947	11.95968	11.95968	3.45554	3.45554
120.6678	9.87823	9.87823	9.31349	9.31349	1.61892	1.61892
140.578	5.98697	5.98697	6.38377	6.38377	0.6371	0.6371

163.7733	2.49479	2.49479	3.66733	3.66733	0.24281	0.24281
190.7959	0	0	1.26869	1.26869	0.13396	0.13396
222.2773	0	0	0	0	0.10624	0.10624
258.953	0	0	0	0	0.06632	0.06632
301.6802	0	0	0	0	0.0302	0.0302
351.4575	0	0	0	0	0	0
409.4479	0	0	0	0	0	0
477.0068	0	0	0	0	0	0
555.713	0	0	0	0	0	0
647.4056	0	0	0	0	0	0
754.2275	0	0	0	0	0	0
878.675	0	0	0	0	0	0

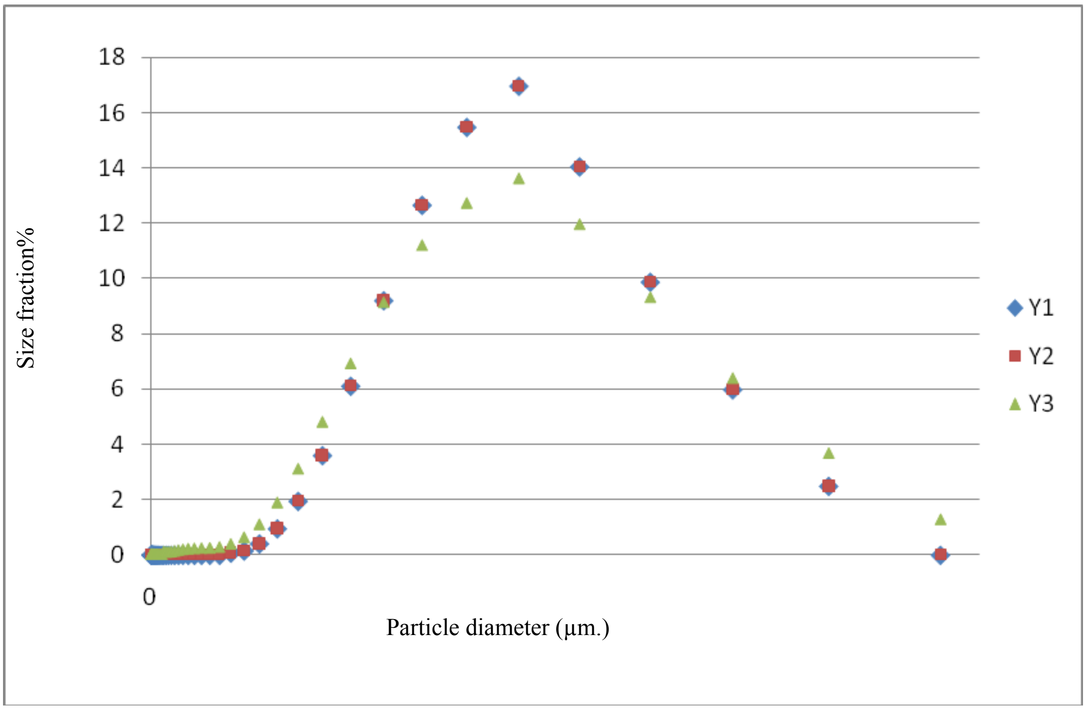

Figure: 3 Particle size distribution before impact.

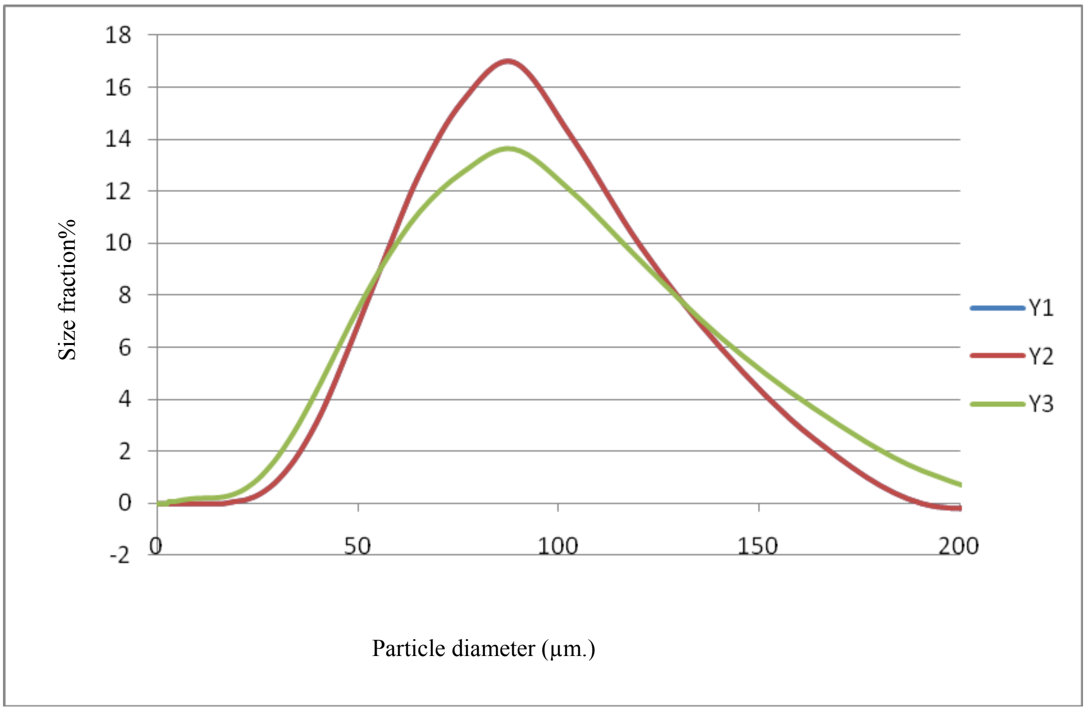

Figure: 4 Particle size distribution before impact.

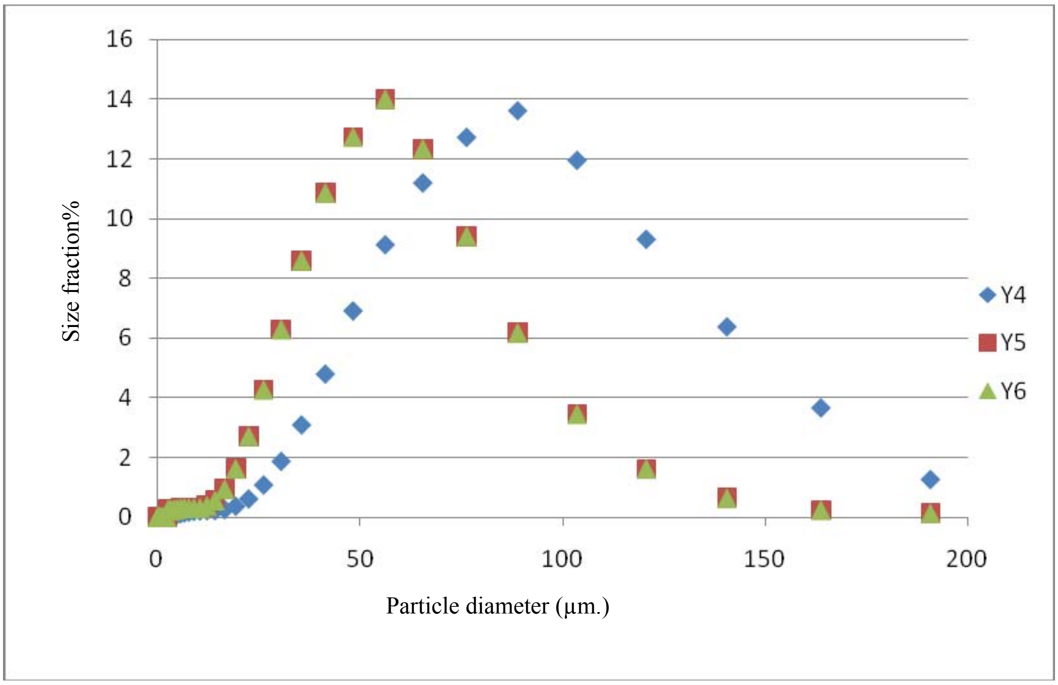

Figure: 5 Particle size distribution after impact.

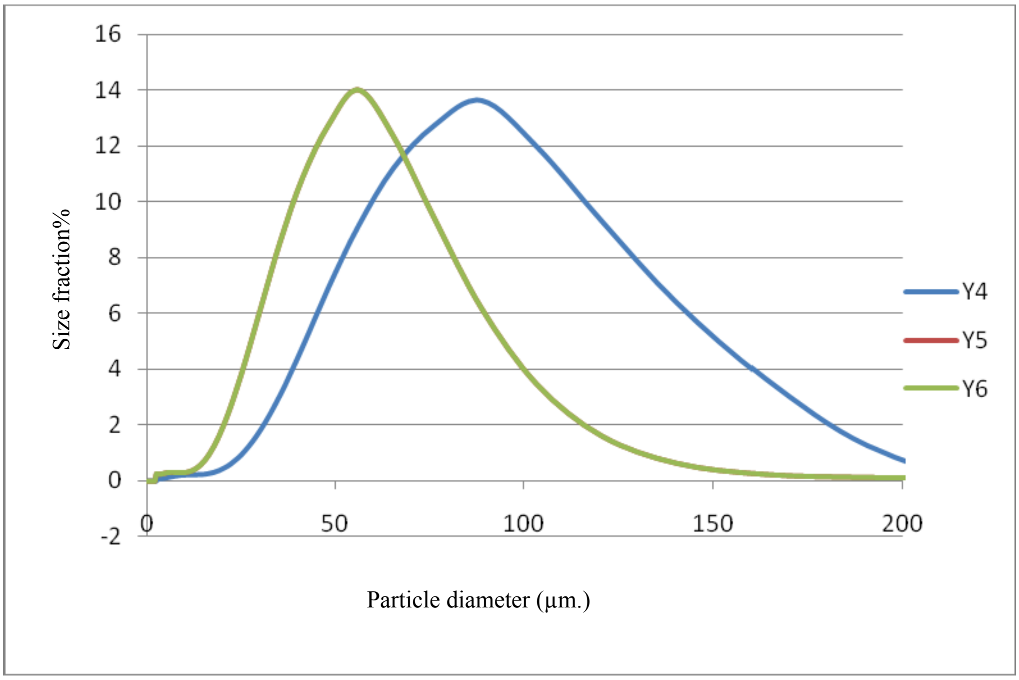

Figure: 6 Particle size distribution after impact.

Discussion

The initial studies on the inherent variability of the tests suggested that the test were able to show a good discrimination between attrited and original alumina. From the Figures 3 and 5 we can see that although the particles diameter show equality before impact but after impact Y1 and Y4 show the similar result where as y2, Y3 and Y4, Y5 show the similar and smaller particle size distribution. Therefore, though the particle size distribution of RS1, RS2 and RS3 are same but FS1 is stronger than FS2 and FS3. The tests were carried out keeping the distance fixed from the end of glass tube to the target. The air stream velocity was also same through the test. These are preliminary results that have explored some of the experimental parameters that affect alumina breakage in the single particle impact rig. Further experiment and work is required to authenticate the test method which will show that the method is reliable for evaluating the alumina strength.

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