Compaction Characteristics of Bottom ash

A Thesis submitted in partial fulfillment of the requirements for the award of the degree

M.TECH DUAL DEGREE

In

Civil engineering

(Geotechnical Engineering)

By

Deepak Kumar

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Rourkela- 769008, India

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Under the supervision of

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CERTIFICATE

This to certify that the thesis entitled "**compaction characteristics of bottom ash** " being submitted by **Deepak Kumar** in the partial fulfillment of the requirements for the award of M. Tech Dual Degree in **Civil Engineering** with specialization in **GEOTECHNICAL ENGINEERING** at the National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in this report has not been submitted to any other university/institute for the award of any degree or diploma.

Prof. Chittaranjan Patra

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National Institute of Technology

Rourkela – 769008

Date:

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Deepak Kumar

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Date:

Abstract:

The present study based on compaction characteristics of Bottom ash. As bottom ash is one of the coal combustion byproducts which is collected at the bottom of the furnace of coal fired thermal power plant which is the main source of production of coal ashes. In this investigation three types of bottom ash have been used. There are several factors which affect the dry density of the bottom ash, as: specific gravity, moisture content, compaction energy, layer thickness and mold area. The variation in the optimum moisture content and maximum dry density of bottom ash (collected from three different sites) as per standard proctor compaction energy is 9.77 -10.46 kN/m^3 and 37-42%, respectively. In the study it has been seen that variation in the above factors affecting the dry density of bottom ash considerably. On the basis of these factors, an empirical model has been developed to calculate the dry density of bottom ash in terms of compaction energy, specific gravity and moisture content. This model might be helpful for engineers to control the compaction in the field and also a preliminary estimation of MDD and OMC of bottom ash on the field.

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Notations

OMC_{proc}	= optimum moister content
MDD_{proc}	= maximum dry density
E	= compaction energy
W	= moisture content
G	= specific gravity
$\acute{y}_d$	= predicted dry density
y_d	= observed dry density
LL	= liquid limit
D_r	= relative density

CHAPTER 1

INTRODUCTION

1. Introduction

Rapid industrialsation and urbanization exert more thrust on power generation sector. Due to the limited scope and limitations experienced by the hydroelectric power generation and atomic power generation sector and/or by virtue of the limited resources or by virtue of increasing public awareness towards the safety of the environment and society, the present day focus is more on coal based thermal power generation. With the increase in the number of coal based thermal power plants worldwide, the problems they enforce, particularly the storage and disposal of coal ashes produced during coal burning, on the environment and biosphere are also becoming more and more acute. If appropriate preventive and corrective measures are not taken in time, a stage may be reached where in the coal ash storage and disposal problem may have to be regarded as a national problem.

Economic development and energy consumption of a country from a country are interrelated. The countries that have achieved higher growth rates with higher per capita income are well ahead of developing countries in terms of their energy consumption. On an average, the per capita energy consumption of India is about 100 times less than that of developed countries such as Norway, Canada, Sweden and USA. However, with the urbanization and industrialsation that are taking place with a tremendous pace, the energy consumption is increasing manifold in India and elsewhere. With the result, the power generation sector in both developing and developed countries is subject to maximum thrust.

At the global level, the hydroelectric power generation sector is receiving relatively lesser importance compared with yesteryears. This is mainly due to increasing public awareness towards preserving the environment and natural resources. Nuclear power is one of the primary source of energy in many developed countries. The running and maintenance of nuclear power plants require utmost care. Any small negligence on the part of the working crew may lead to catastrophe that endangers the public life and the environment of a considerably vast area, as has happened in Chernobyl of erstwhile USSR. Being the sources of serious threat to very existence of life on earth, the nuclear power plants are receiving a lot of protest from the technologically awakened public even in the developed countries. Coupled with this, lack of resources and technological limitations have forced the developing and underdeveloped and even developed countries to either abandon or to turn away from such projects and to look for other alternate source of energy. Even though oil and natural gas form the major sources of energy in the developed countries, factors such as non-local availability and financial restraints limit their use in most of the developing and under developed countries. This has forced the attention to focus on coal as the viable source of energy.

Coal is the main source of energy in numerous countries as India (about 70%), Pakistan (about 63 %) and China (about 80%), at the worldwide level, coal has the part of nearby 38% to 40% as the source of energy. India counted as the fourth largest coal producer worldwide (after the United States, China and Australia). Presently, Indian coal reserves are estimated to be around 212 billion tones.

An efficient and successful handling of highly complex coal ash related problems is possible only when one understand the basics of such problems. The major problem the thermal power generation sector is facing is the disposal of high quantum of coal ashes produced. For the proper implementation of their bulk utilization schemes in the field of geotechnical engineering, a relatively good knowledge of the characteristics of coal ashes, their response and engineering behavior in the field is highly essential.

CHAPTER 2

LITERATURE REVIEW

2.1 Literature review

2.1.1 Introduction

The solution to handle the problems related to the disposal of the huge quantities of coal ashes produced in thermal power plants require strategies to motivate and encourage the bulk utilization of coal ashes through technological feasible, cost effective and eco-friendly field applications. There is an ample scope for the bulk utilization of coal ashes in geotechnical applications such as construction of embankments, back filling, construction of roads and the like. A thorough understanding of the engineering behaviour of coal ashes is very much essential during planning and execution of such projects.

Some correlations are following:

Lisa et al. (1998) described a method for estimating MDD ($Y_{d\ max}$) and OMC (w_{opt}) of soils (clayey) at any compactive energy E. One method was based on liquid limit (LL) and compaction curve, whereas another based on LL only. Linear relations between $Y_{d\ max}$ and log E, and W_{opt} and log E, both are a function of the liquid limit which used to extrapolate to different compaction energies.

If the LL and compaction curve known,

Then,

$$Y_{d\ max,\ E} = Y_{d\ max,\ k} + (2.27\ LL - 0.94) \log (E/E_K) \qquad (1)$$

$$W_{opt,\ E} = w_{opt,\ k} + (12.39 - 12.21LL) \log (E/E_K) \qquad (2)$$

And,

If only LL is known then,

$$Y_{d\ max,\ E} = (2.27 \log LL - 0.94) \log E - 0.16LL + 17.02 \qquad (3)$$

$$W_{opt,E} = (12.39 - 12.21 \log LL) \log E + 0.67LL + 9.21 \quad (4)$$

Omar et al. (2003) studied modified proctor compaction test results of 311 soil samples, 45 were gravelly soils and 364 were sandy soils. The compaction test was done according to ASTM 1557 method C (modified proctor test) to avoid oversize correction. Based on result the following correlation were developed:

$$p_{d\,(max)}\,(kg/m^3) = [4,804,574\ G_s - 195.55(LL)^2 + 156,971(R\#4) - 9,527,830]^{.5} \quad (5)$$

$$Ln\,(w_{opt}) = 1.195*10^{-4}\,(LL)^2 - 1.94\ G_s - 6.617*10^{-5}\,(R\#4) + 7.651 \quad (6)$$

Where

$p_{d\,(max)}$ = maximum dry density

w_{opt} = optimum water content (%)

G_S = specific gravity of soil solids

R#4 = percent retained on No. 4 sieve

Here no attempt was made to correlate the optimum moisture and maximum dry density contents with the energy of compaction.

Bera et al. (2007) showed correlation between dry density and moisture content and also specific gravity of pond ash (all test was conducted in proctor mold. He developed a linear model for dry density (y_d) in terms of log (E), w (moisture content), and G (specific gravity).

$$y_d = 1.53512 \log (E) + 0.02754*w + 30.33238*G - 61.24920 \quad (7)$$

Osman et al. (2008) studied a number of compaction test results on fine grained (cohesive) soil, including those provided by Gurtug and Shridharan (2004). On the basis of study, the following correlation were developed:

$$w_{opt}\,(\%) = (1.99 - 0.165\ln E)\,(PI) \tag{8}$$

$$y_{d\,(max)}\,(KN/m^3) = L\text{-}M\,w_{opt} \tag{9}$$

Where,

$$L = 14.34 + 1.195\ln E \tag{10}$$

$$M = -0.19 + 0.073\ln E \tag{11}$$

PI = Plasticity index (%)

E = compaction energy (KN-m/m^3)

Patra et al. (2010) conducted standard and modified proctor tests (ASTM test designation D-698 and D-1557 respectively) on 55 sand samples to estimate maximum and minimum void ratio ($e_{max,}$ e_{min}) and the void ratios at the OMC from standard and modified proctor compaction tests (e_s and $e_{m)}$.the void ratios and hence, relative density of compaction (D_r) have been correlated to the median grain size (D_{50}) of soils.

Modified proctor test:

$$D_r = .8321 D_{50}^{\,-.087} \tag{12}$$

Standard proctor test:

$$D_r = .5864 D_{50}^{\,-.107} \tag{13}$$

Patra et al. (2010), experiments done on 55 clean sand samples from "reduced" standard (number of hammer blows/layer =15 with E=360 KN-m/m^3 approximately) and modified (blows =12, E=1300 KN-m/m^3 approx.) proctor test and correlation developed between D_r, D_{50} and the compaction energy (E),

$$D_r = AD_{50}^{-B} \text{ (Modified proctor test)} \quad (14)$$

Where,

$$A = 0.216\ln E - 0.850 \quad (15)$$

$$B = -0.03\ln E + 0.306 \quad (16)$$

2.1.2 Different studies on Bottom ash

Seals (1974) stated that the bottom ash can be used as engineering material, he collected samples from state of West Virginia and the nearby area. The samples have been teste to identify the engineering property, classification, and identification. Several tests have been done for identification as: chemical analysis, specific gravity, grain size distribution. Many tests also performed to estimate bottom ash as construction material included: standard proctor compaction, shear strength, constant head permeability, relative density, one dimensional compression, Los Angeles abrasion test, and sulphate soundness. After performing all the tests, it was found that bottom ash can be used as an aggregate, as bottom ash from other sites satisfied specification given which are related to use of the material. The behavior of sand and bottom ash also compared and it was found similar.

Rogbeck and knutz (1996) have used bottom ash in construction as a land fill material. The requirement of recycling the waste material among them bottom ash is major waste material. This can be used as land fill material by testing it environmental acceptability and also by combining it by other material.

Kayabal & Bulus (2000) have used bottom ash from four power plants as a landfill bottom liner and construction fill. They embedded bottom ash with different matrix material, for that they use bentonite (powdered), natural clay, and construction lime. For the different ratios of matrix and bottom ash, compaction tests have been performed. The OMC varies between 40 to 45% and dry density yielding at ca 1 mg-m^{-3}. Triaxial compression tests showed shear strength an 11-fold increase for cured specimen. The permeability of mixtures was mostly ca 10^{-4} cm/s, which is cannot be considered enough for landfill liner. Leaching tests also performed using deionized water to see the influence of leachate produced from the mixtures. An environment friendly and light density mixture has determined and suggested for construction fill material.

Kim (2005) have used mixture of bottom ash and fly ash for use as a construction material for highway embankments. Class F fly ash and Bottom ash were collected from two utility power plants in Indiana and tests were performed for mechanical properties as: strength, stiffness, permeability, compaction, compressibility. Three different ratios of bottom ash and fly ash have been used and mixed (i.e., 50, 75 and 100 % fly ash by weight) were arranged for analysis. It has been concluded that moistures of ash compare constructively with conventional granular material.

Kurama and Kaya (2008) this study aims to assess the usability of bottom ash, brought from Tuncbilek Power, Station-Turkey**,** for use in concrete industry. In this study, the bottom ash was used about 25 % as a partial substitute for the Portland cement. To decrease the unburned carbon content, ash was subjected to three different procedures (heavy medium separation, particle size classification, and electrostatic separation). On the basis of results it concluded that by replacing the bottom ash up to 10% with Portland cement, could enhanced the mechanical properties of concrete, which results that it can be useful for concrete industry.

Andrade (2009) has analyzed the influence of bottom ash on fresh properties of concrete when used as fine aggregate. Here author tried to replace natural fine aggregate with bottom ash. Many tests were performed for water loss, setting time, and plastic shrinkage, in presence of CBA to analyze the material. The effect of bottom ash porosity on water loss and water absorption of the material and water consumption of bottom ash-concrete mixture, also discussed. The results conclude that the bottom ash produced with concrete are vulnerable to bleeding and with increment in percentage of bottom ash as a natural sand alternative, decrement in deformation by plastic shrinkage occurred. It was also seen decrement in setting, which is due to presence of CBA in concrete. In conclusion, various type of bottom ash mix result in concretes with different properties in the fresh state, but the behavioral tendencies are maintained when bottom ash is employed as a replacement for natural aggregates.

Singh & Siddique (2014) have studied the effect of CBA as partial replacement of aggregate on micro-structural properties and strength characteristics of concrete. They have performed experiments to see the effect of bottom ash on the properties of hardened and fresh concrete which contain bottom ash. The properties i.e. splitting tensile strength, unit weight, and compressive strength, modulus of elasticity and micro-structure of concrete combining with bottom ash in full or partial replacement of sand were tested and has compared with conventional concrete. Workability and bleeding of concrete also examined after mixing of bottom ash instead of river sand. The results indicated that at a particular water-cement ratio, loss of water and workability decreased with the usage of bottom ash instead of river sand in concrete. After 28 days of curing of bottom ash concrete compressive strength was not affected much. However, it surpassed the conventional concrete compressive strength after 90 days curing. Moreover, splitting tensile strength increased and modulus of elasticity decreased at each curing period of concrete. XRD and SEM tests indicate the less monolithic structure of C-S-H gel than that of control concrete with bottom ash ettringite intensity was not changed.

2.1.3 Utilization of bottom ash

From above literature studies, it can be said that bottom ash can use for various purpose which are:

1. Partial replacement of fine aggregate
2. Can be used as construction material
3. As a substitute of Portland cement
4. In noise barrier
5. Construction fill and landfill bottom liner etc.

CHAPTER-3

EXPERIMENTAL WORK AND METHODOLOGY

3.1 Introduction

From three sites bottom ash was collected, various experiments have been done in order to determine Geotechnical properties of bottom ash like specific gravity, grain size analysis, optimum moisture content, maximum dry density, cohesion value and internal angle of friction of bottom ash. To see the effect of compaction controlling parameter on dry density of bottom ash, the variation has been given in compaction energy, layer thickness, mold area, specific gravity and moisture content. Also, in order to see variation in internal angle of friction of bottom ash, bottom ash is compacted at different compaction energies. The experiments which have been done in order to check changes in behavior of bottom ash are following:

3.2 Material Used

3.2.1 Bottom ash

From three different sites bottom ash has been collected. The three sites are, NTPC-SAIL power company pvt. ltd. (NSPCL) Rourkela, Vedanta, Jharsuguda and Aditya Alumina, lapanga Sambalpur.

3.2.2 Sampling

The samples were oven dried for 105-110 degrees and sieved from 4.75 mm IS sieve for compaction tests, strength parameters and permeability and 2 mm IS sieve for specific gravity.

3.3 EXPERIMENTAL WORK

3.3.1 Specific gravity

Specific gravity of bottom ash was determined as per IS: 2720 (Part-III, section-1)1980. In which 50g sample of bottom ash oven dried up to 105-110 degrees has been used passed through 2 mm IS sieve and weighed nearest 0.001g. Three density bottles (pycnometers) of 50 ml capacity, a desiccator, and heater for heating the density bottle in order to remove air bubbles and distilled water.

For determining the specific gravity, first three density bottles have been taken and weighed nearest to 0.001g. Then 50g oven dried bottom ash was taken passed through 2 mm IS sieve, weighed nearest to 0.001g. Then sample and pyknometers both weighed together, then weight of pyknometers and distilled water was taken. Using the formula provided by IS: 2720 (Part-III, section-1)1980 specific gravity was determined.

3.3.2 Grain size analysis:

Grain size analysis was done according to IS code: 2720(part 4)-1985. For sieve analysis 500g oven dried sample was taken and passed through sieve set which is: 4.75 mm, 2 mm, 1 mm, 600 µ, 425 µ, 300 µ, 212 µ, 150 µ, 75 µ. The weight of retained material was taken after that graph has been plotted between percentage passing and diameter of particle. Hydrometer analysis was performed for the particle which is passed through 75 µ size sieve. A graph was plotted between % finer and diameter of particles. Later both the graph was merged and by using the relationship between % passing and diameter of particle coefficient of curvature (C_c) and uniformity coefficient (C_u) was calculated.

3.3.3 Permeability

Permeability was determined of bottom ash as per IS: 2720(part 17)-1986. Permeability is a factor with which water can flow through the ash or soil due to interconnected voids. It's necessary for estimate the quantity of seepage under different hydraulic conditions, for investigating stability analysis of earth-retaining structures and earth dams which subjected to seepage. There are two methods by which hydraulic conductivity can be determined say: **Constant head test** and **Falling head test.** As per present investigation hydraulic conductivity was determined by constant head test in which head was remained constant between inlet and outlet of arrangement of the test.

3.3.4 Direct shear test

The strength parameters c and Φ are determined by direct shear test which is done according to IS: 2720(part 13) 1986. This test consists a box which has the dimension 60×60×50 mm. A specimen was prepared at MDD obtained at OMC and later sheared keeping strain content for variable normal stress. A graph was plotted between shear stress vs normal stress. And cohesion (c) and angle of internal friction (Φ) found out from the graph. The values of c and Φ was obtained at light compaction energy as well as heavy compaction energy.

3.3.5 Determination of void ratio:

3.3.5.1 *Determination of maximum void ratio*

Determination of void ration was done (as per IS: 2720 – Part XIV, 1983). For determining the maximum void ratio (minimum dry density) oven dried sample of bottom ash was taken. The maximum void ration was determined by pouring the bottom ash in a mold using pouring device, while spout was adjusted at 25 mm free fall height, a mold which has volume 3000 cm^3 was used.

The volume and weight of the poured bottom ash was found out and maximum void ratio or minimum dry density of bottom ash was determined and later by using minimum dry density maximum void ratio was determined using formula which is given in IS: 2720 – Part XIV, 1983.

3.3.5.2 Determination of minimum void ratio

The maximum dry density (minimum void ratio) was determined either by the dry method or the wet method (as per IS: 2720 – Part XIV, 1983). In the dry method the mold was filled thoroughly with mixed oven dried bottom ash. A surcharge load was placed on the ash surface and the mold was fixed to a vibrating table. The specimen was vibrated for 8 minutes. The weight of the dry bottom ash in the compacted state was found and maximum dry density determined from which minimum void ratio was calculated.

3.3.6 XRD test

The x-ray diffraction (XRD) test was conducted to determine the crystalline peaks that appeared at different curing periods. This is performed by using Philips X' PERT system X-Ray Diffractometer. Samples were grounded to sizes less than 75 micron before being used for XRD analysis. The specimen was placed in the Diffractometer and scanned using Cu Kα radiation, a step size of 0.02^o.

3.3.7 Compaction test:

The compaction of bottom ash has been done according to IS: 2720 (part 7)-1980 for light compaction and IS: 2720(part 8)-1983 for heavy compaction. Compaction is a process if densification of a granular material by the application of mechanical energy. This process involves packing the granular material together with the reduction in the volume of air voids. The densification of the granular material controls its other engineering properties as shear strength, compressibility and permeability. The dry density of the compacted material is a measure of the degree of compaction achieved. This is the function of the amount and method of energy application, water content adopted during compaction and material characteristics such as grain size distribution, specific gravity, gradation, particle shape and plasticity.

In the laboratory, the standard proctor compaction test was conducted using a mold of 100 mm diameter, 127.3 mm height and 150 mm diameter, 127.3 mm height in order to give variation in mold area. A rammer of 2.6 kg mass with a fall of 310 mm was used to compact the ash in the mold in three layers, each layer being subjected to 25 blows of the rammer. The modified proctor compaction test makes use of the same mold in five layers with rammer of 4.9 kg mass and a fall of 450 mm by providing 25 blows/layer.

Compaction test: in proctor mold, in CBR mold.

Testing the effect of compaction controlling parameters on dry density of variation of these Parameters are:

A). Variation in compaction energy (up to four energy levels).

B). Variation in layer thickness.

C). Variation in compaction area.

D.) Variation in specific gravity (as bottom ash collected from different power plant, so specific

Gravity can be different for each plant)

CHAPTER – 4
RESULT AND DISCUSSION

4.1 INTRODUCTION

When pulverized coal is burnt, about 80% of the unburned material is entrained in the flue gases and is recovered as *fly ash*. The remaining 20% of the unburned granular material that is coarse in size is collected from the bottom of the furnace is called *bottom ash*.

Tests have been done to determine the index properties as well as chemical composition and engineering properties. The results are given in detail and discussed in this chapter.

4.2 Index properties:

4.2.1Specific gravity

Specific gravity of coal ash primarily depends on its chemical composition. Generally coal ashes having low value of specific gravity when compared with those of soils that have specific gravity varying in a narrow range of 2.6-2.8. Specific gravity of Indian bottom ashes varying in rage of 1.64-2.66 (A. Shridharan and K. Prakash), an exceptionally high value of specific gravity of one of the bottom ashes from USA (i.e., 2.78) is due to the presence of high iron content of about 14.3%.

In this study three types of bottom ash was collected and their specific gravity was found out as per IS: 2720 (Part-III, section-1)1980 are shown in Table 1.

Table 1: Specific gravity of bottom ash collected from three different sites

Bottom ash	Specific gravity
NSPCL, Rourkela	2.08
Vedanta, Jharsuguda	2.10
Aditya Alumina, Lapanga Sambalpur	2.13

There is not much difference occurred in specific gravity of bottom ashes but these are lying within the range of 1.64-2.66 (A. Shridharan and K. Prakash) of Indian bottom ashes.

4.2.2 Grain size analysis

The grain size analysis of coal ashes can be done in accordance with IS: 2720(part 4)-1985. Dry sieving can be adopted for gravel sized coal ash sample (i.e., sample retained on 4.75 mm sieve). Wet sieving can be adopted for sand sized coal ash samples (i.e., samples passing 4.75 mm sieve and retained on 4.75 mm sieve). Hydrometer can be done on samples passing 75-micron sieve. The hydrometer analysis shall be done using dispersion agents. As coal ashes are sand and /or silt sized non-cohesive materials, the effect of dispersion agents on grain size distribution of coal ashes is negligible. Hence, the use of dispersion agents in the hydrometer analysis can be dispensed with (Shridharan et al. 2001).

Grain size distribution curve was found of samples collected from three different sites. As grain size distribution depends on degree of pulverization of coal and firing temperature of boiler unit, variation grain size distribution curve plotted in fig: 1.

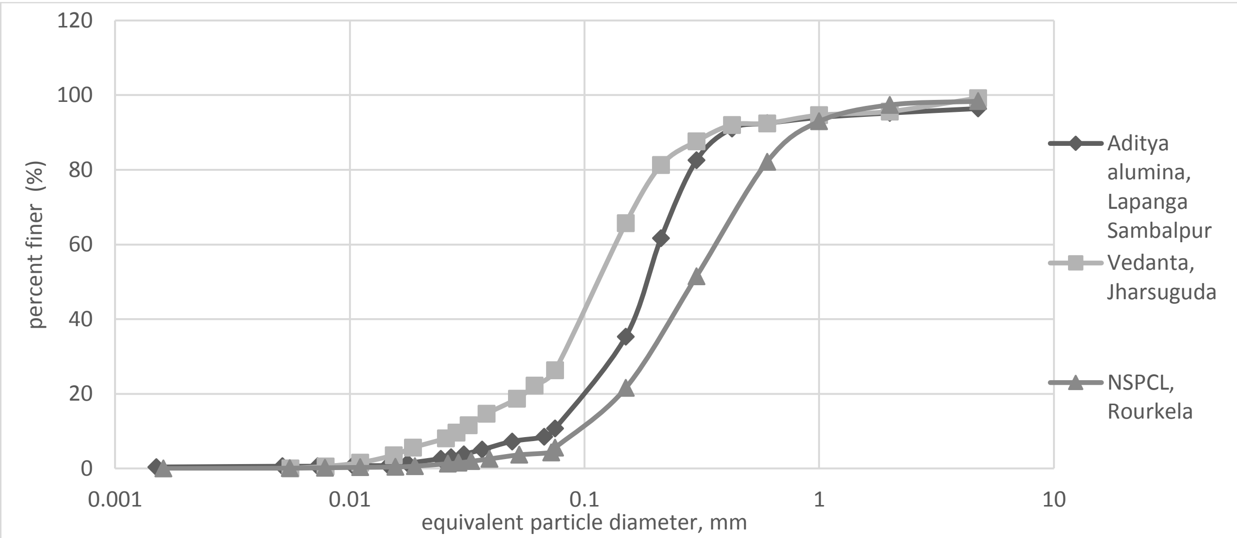

Figure 1: Grain size distribution curve of bottom ashes

Table 2: Uniformity coefficient and coefficient of gradation of bottom ash

Bottom ash	Uniformity coefficient (C_u)	Coefficient of curvature (C_c)
NSPCL, Rourkela	4.06	1.18
Vedanta, Jharsuguda	5.33	1.33
Aditya Alumina, Lapanga Sambalpur	2.86	1.60

If $C_u > 6$, $1 < C_c > 3$, then such particle considered as well graded. From above values given in Table 2, it's clear that none of above ashes are well graded. Uniformity coefficient and coefficient of curvature is calculated by using formula below:

Coefficient of curvature, $C_C = D_{60} / D_{10}$

Uniformity Coefficient, $Cu = D_{30}^2 / (D_{60} \times D_{10})$

4.3 Mineralogy Test

From XRD analysis, it is found quartz and mulite are present in raw materials all three bottom ashes but in case of Bottom ash collected from NSPCL, presence of hematite is also found.

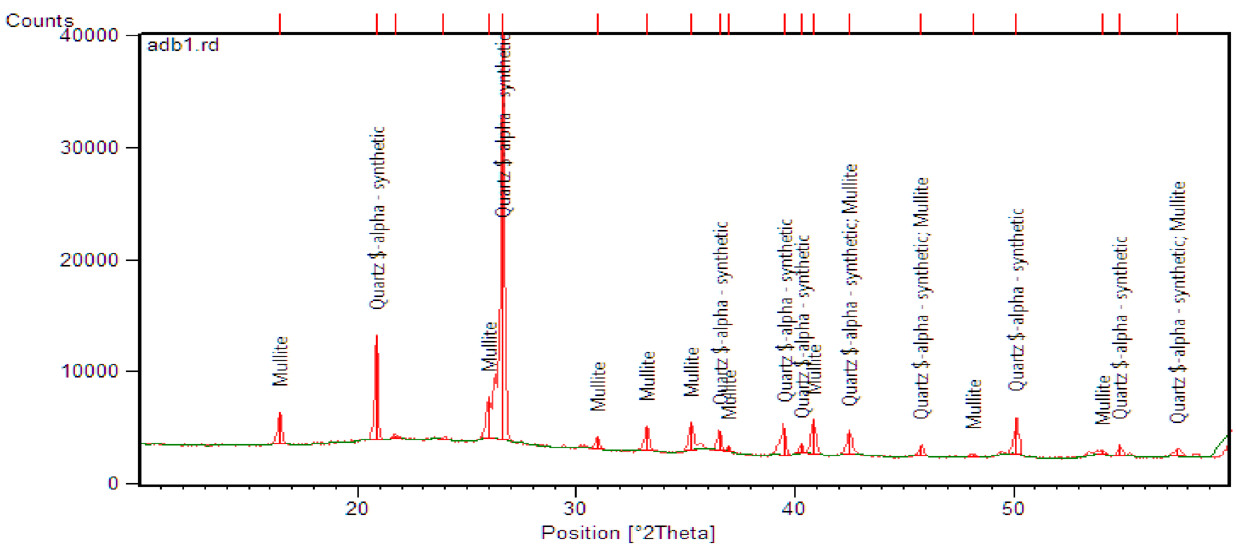

Figure 2: XRD analysis of bottom ash from Aditya alumina, Lapanga Sambalpur

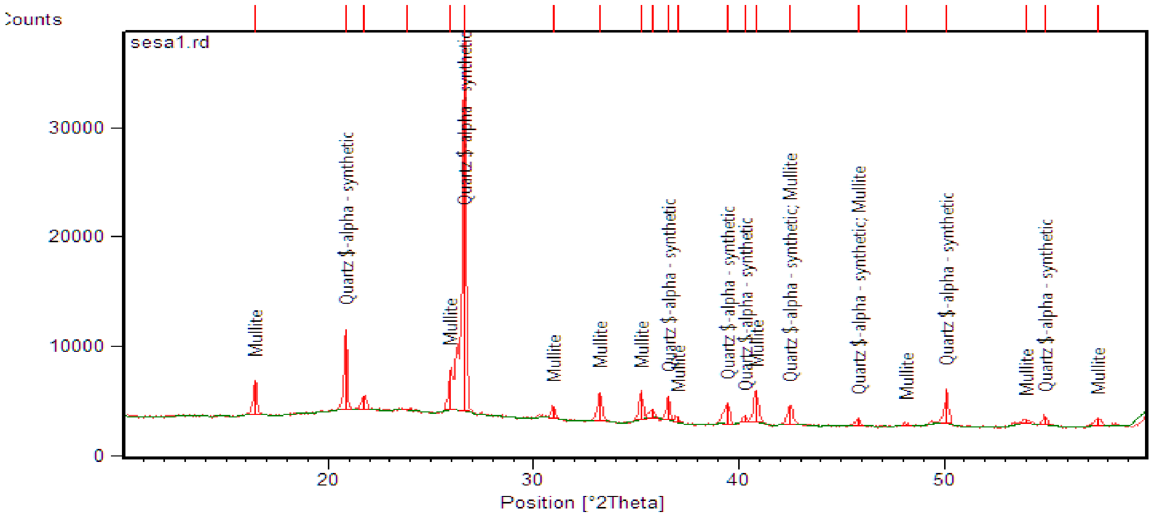

Figure 3: XRD analysis of bottom ash from Vedanta, Jharsuguda

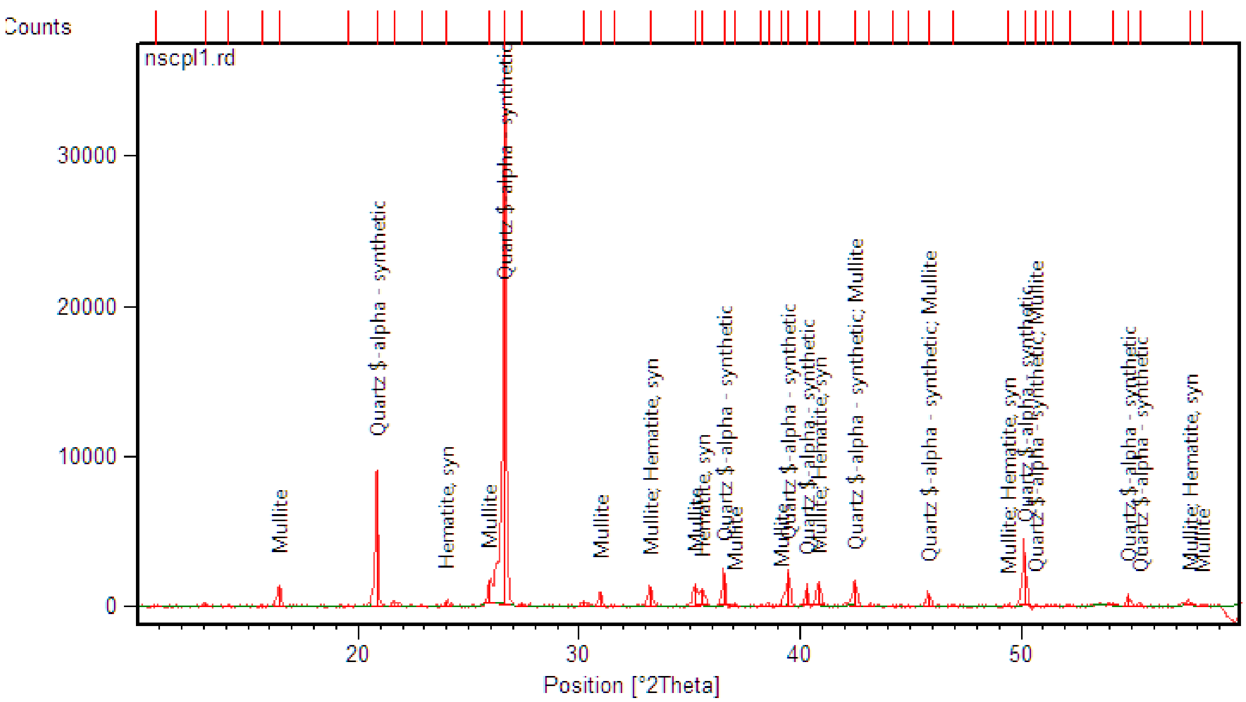

Figure 4: XRD analysis of bottom ash from NSPCL, Rourkela

4.4 Engineering properties:

4.4.1Direct shear test

Direct shear value of bottom ash: The ash was compacted at OMC_{Proc} (with standard proctor compaction energy). The direct shear values have been found out of bottom ash according to IS: 2720(part 13) 1986. In this test, the sample is subjected to a shear stress under a constant normal stress, which mobilizes the shear stresses in the sample across a predefined failure plane. The data from direct shear box test are plotted in the form of failure envelop on shear stress Vs normal stress plot, the scale of plotting along both the axes being the same. In Table 3, the values of strength parameters has been shown as well as the failure envelop of bottom ash also plotted in fig 5, 6, and 7.

Table 3: strength parameters of bottom ash

Bottom ash	Angle of internal friction (Φ)	Cohesion (kPa)
NSPCL, Rourkela	34	15.34
Vedanta, Jharsuguda	33	18.23
Aditya Alumina, Lapanga Sambalpur	33	20.55

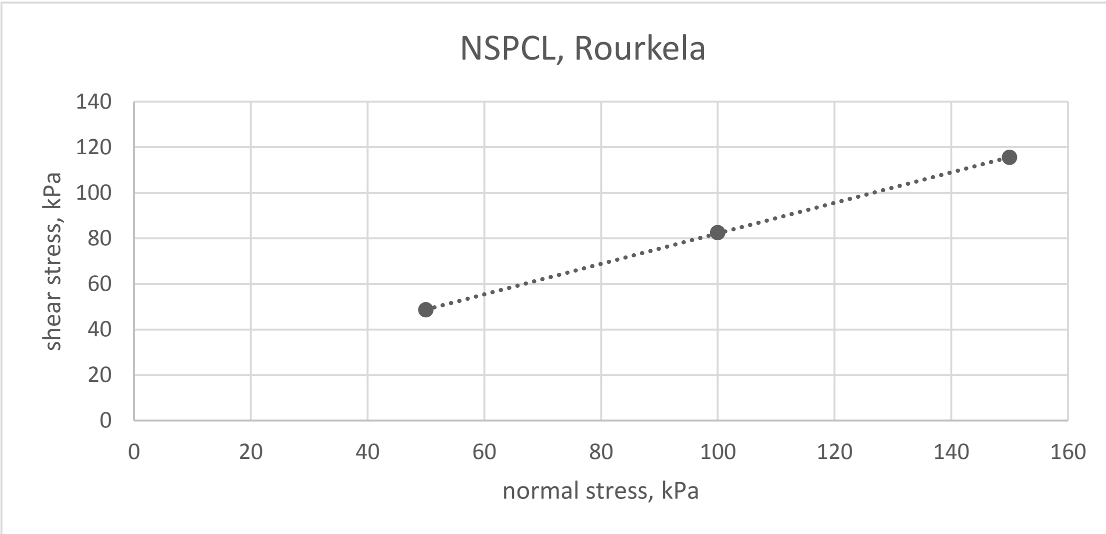

Figure 5: Direct shear test of NSPCL, Rourkela

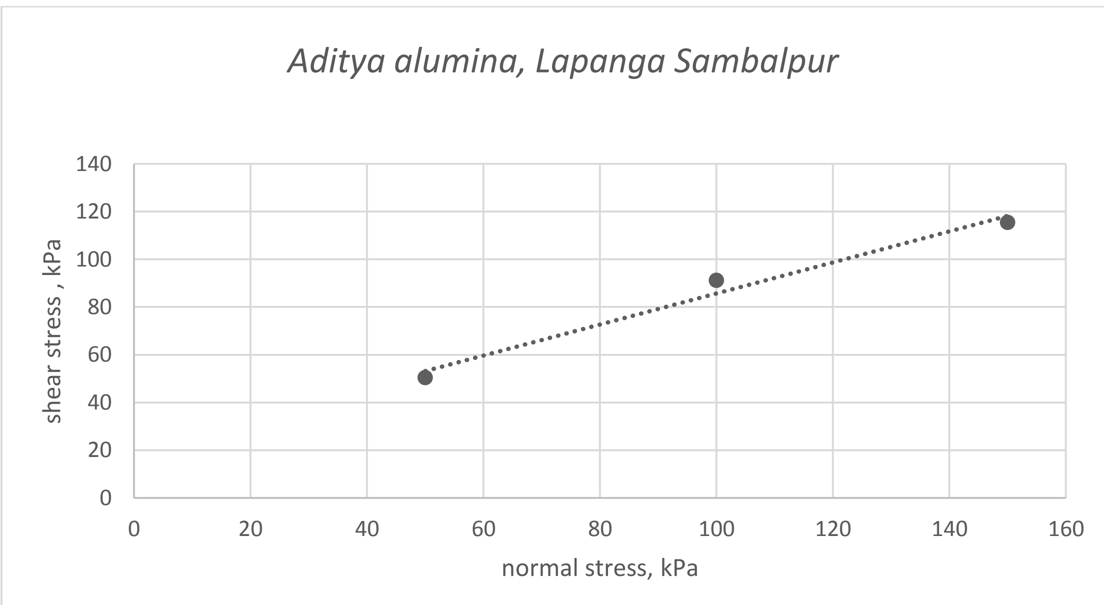

Figure 6: Direct shear test of Aditya Alumina, Lapanga (sambalpur)

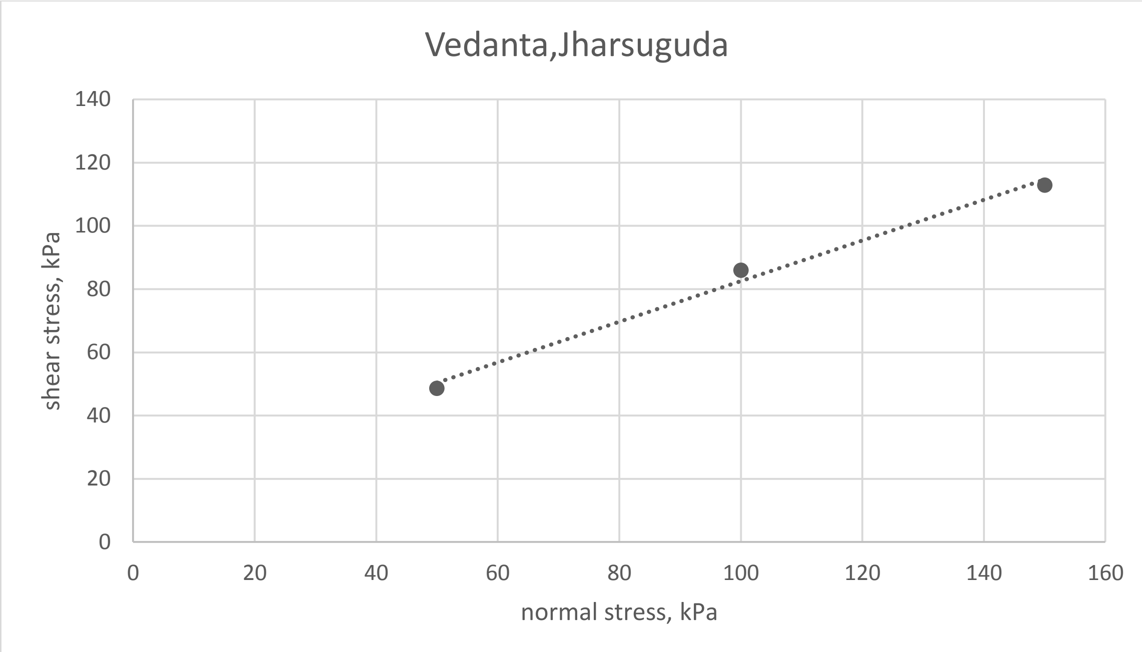

Figure 7: Direct shear test of Vedanta, Jharsuguda

4.4.2Determination of Void ratio:

4.4.2.1Determination of maximum void ratio

In this process, to find out the maximum void ratio, bottom ash was poured loosely in the mould with much care without disturbing the mold, the pouring was done by a pouring device which has a diameter of 25mm, the pouring was done from a constant fall of 25 mm. the mold was filled 25 mm approximately above the top of the mold and was leveled with a spatula. Later mass of bottom ash filled in mold and volume of the mold was noted. The value of maximum void ratio is given in Table 4.

4.4.2.2Determination of minimum void ratio

In order to find, the minimum void ratio, bottom ash was filled in the mold arrangement of vibratory table, after filling the bottom ash a surcharge base plate and a weight of 14kg above plate, was placed and mold was hooked on the vibrator table. The vibrator control was set to 8 minutes and vibrated. Later mass compacted of bottom ash was taken and minimum void ratio calculated. The minimum void ratio is given in Table 4.

Table 4: Maximum and minimum void ratio of bottom ash

Bottom ash	e_{max}	e_{min}
NSPCL, Rourkela	1.590	1.202
Vedanta, Jharsuguda	1.593	1.234
Aditya Alumina, Lapanga Sambalpur	1.027	0.855

4.4.3Permeability

To find out hydraulic conductivity of bottom ash, first oven dried sample was taken and compacted in the permeability mold at OMC_{proc} by giving standard proctor compaction energy. After compacting the bottom ash in the mold, the base plate was removed and two porous stone was placed at the top and bottom of the mold with filter paper on it. After setting the permeability mold, compacted sample was set for saturation and after saturation, mold was placed under constant head permeability test arrangement and reading was taken.

The permeability of bottom ash collected from three different sites is presented in Table 5.

Table 5: Hydraulic conductivity of bottom ash

Bottom ash	Permeability (cm/sec)
NSPCL, Rourkela	1.2×10^{-3}
Vedanta, Jharsuguda	1.4×10^{-3}
Aditya Alumina, Lapanga Sambalpur	2.5×10^{-3}

4.4.4Compaction test

Compaction was done in two different mold to give the variation in compaction area as 1.Proctor mold, 2. CBR mold. And that for each compaction mold, compaction energy variation has been given. The variation in compaction energy was controlled by giving variation in number of blows/layer for standard proctor test and modified proctor test.

4.4.4.1Compaction in proctor mold

Compaction test has been done in proctor mold with variation in compaction energy .as it is one of the parameters that influences the dry density of soil. The proctor mold which used has 10 cm diameter, and 12.7 cm height which has volume of 997.45 $cm^{3.}$ The weight of the hammer was 2.6 kg and height of fall 31 cm taken, and used for compacting the ash. The following compaction energies was used to compact the ash.

- Standard proctor test with 25 blows/layer, compaction energy = 594.5 KN-m/m^3.
- Reduced Standard proctor test with 15 blows/layer, compaction energy = 356.71 KN-m/m^3.
- Modified proctor test with 25 blows/layer, compaction energy = 2710.8 KN-m/$m^{3.}$
- Reduced modified proctor test with 12 blows / layer, compaction energy= 1301.2KN-m/m^3.

By variation in compaction energy change in dry unit weight was occurred. From plotted curves it can be seen due to increase in compaction energy, the dry density of bottom ash increased with decrease in moisture content of bottom ash. Closer packing of particle occurred due to increase in compaction energy this results increase in dry density of bottom ash until a critical point of dry density reaches. Bailey and Leonards' (1982) observed the same behavior while compacting the pulverized coal ash. The change in dry density of bottom ash due to increase in compaction energy is shown in Fig (5), (6) ,(7) for Aditya Alumina (Lapanga Sambalpur), Vedanta (Jharsuguda) , NSPCL (Rourkela) respectively .

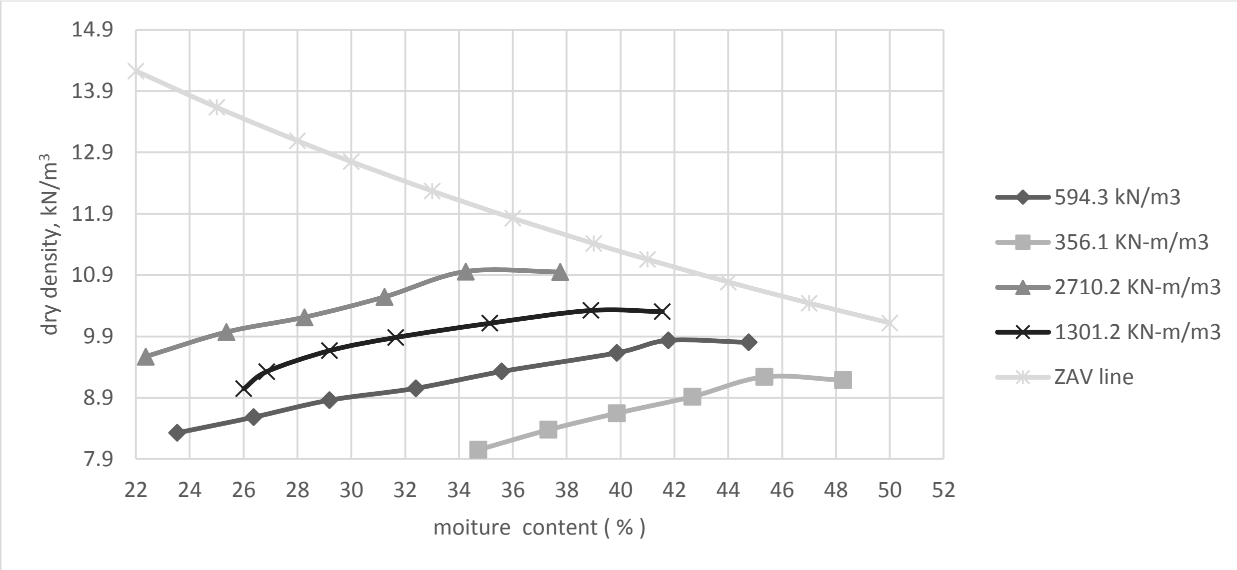

Figure 8: Variation in dry density with change in compaction energy (Aditya alumina, Lapanga Sambalpur)

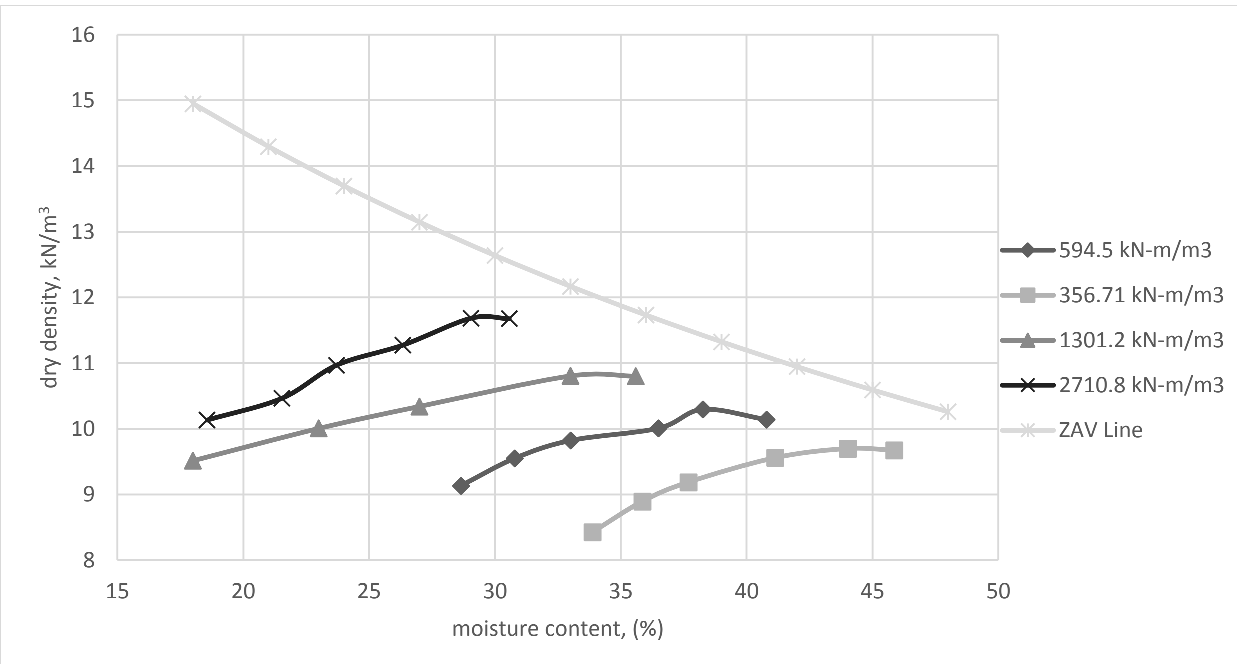

Figure 9: Variation in dry density with change in compaction energy (Vedanta, Jharsuguda bottom ash)

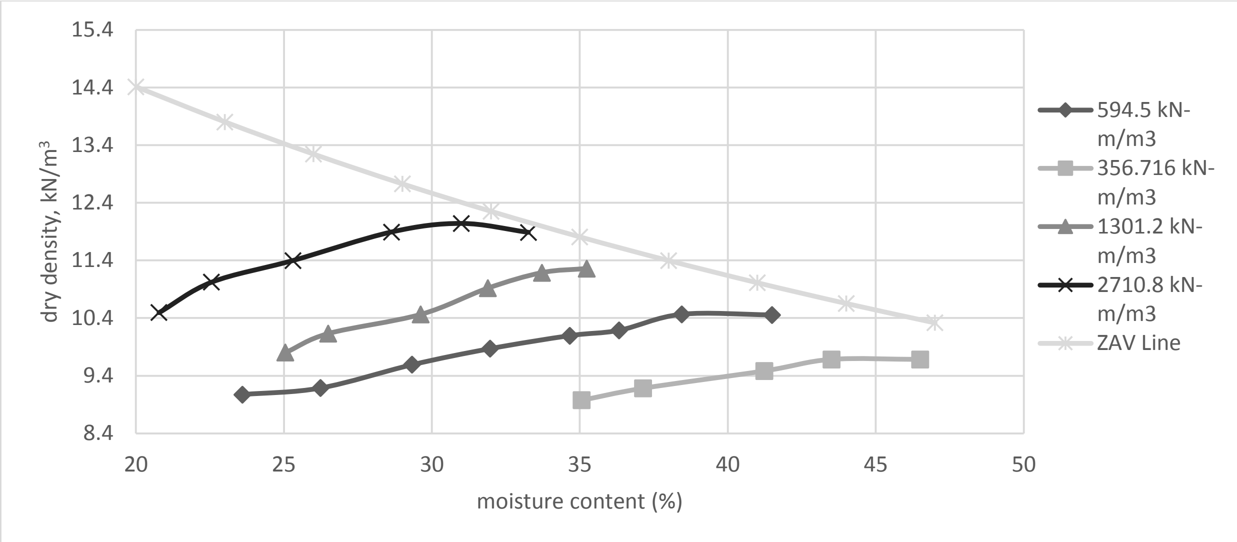

Figure 10: Variation in dry density with change in compaction energy (NSPCL, Rourkela bottom ash)

4.4.5Change in grain size of bottom ash

Modification in grain size distribution also estimated after compacting the bottom ash at different compaction energy which is shown in following fig 11, 12, 13 of bottom ash from Aditya Alumina (lapanga Samblapur), Vedanta (Jharsuguda), and NSPCL (Rourkela), respectively. The change in median grain size of each bottom ash was after compaction from 0.19 to 0.1 mm, .012 to 0.1, and 0.19 to 0.13 mm of bottom ash from Aditya Alumina (lapanga Samblapur), Vedanta (Jharsuguda), and NSPCL (Rourkela).

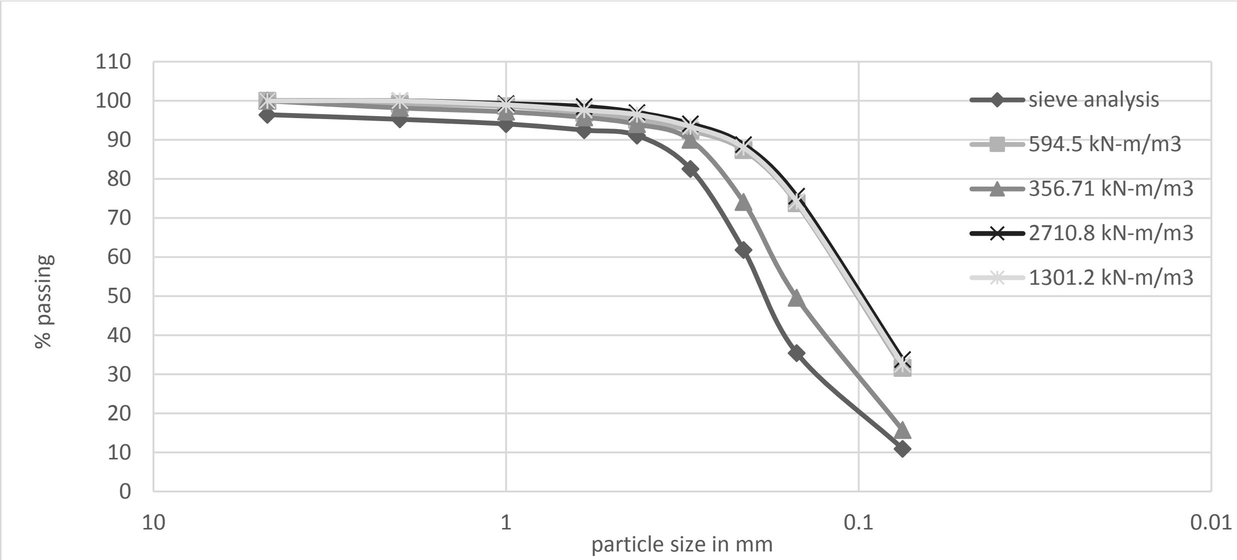

Figure 11: Sieve analysis of bottom ash after applying different compaction energy (Aditya alumina, Lapanga Sambalpur)

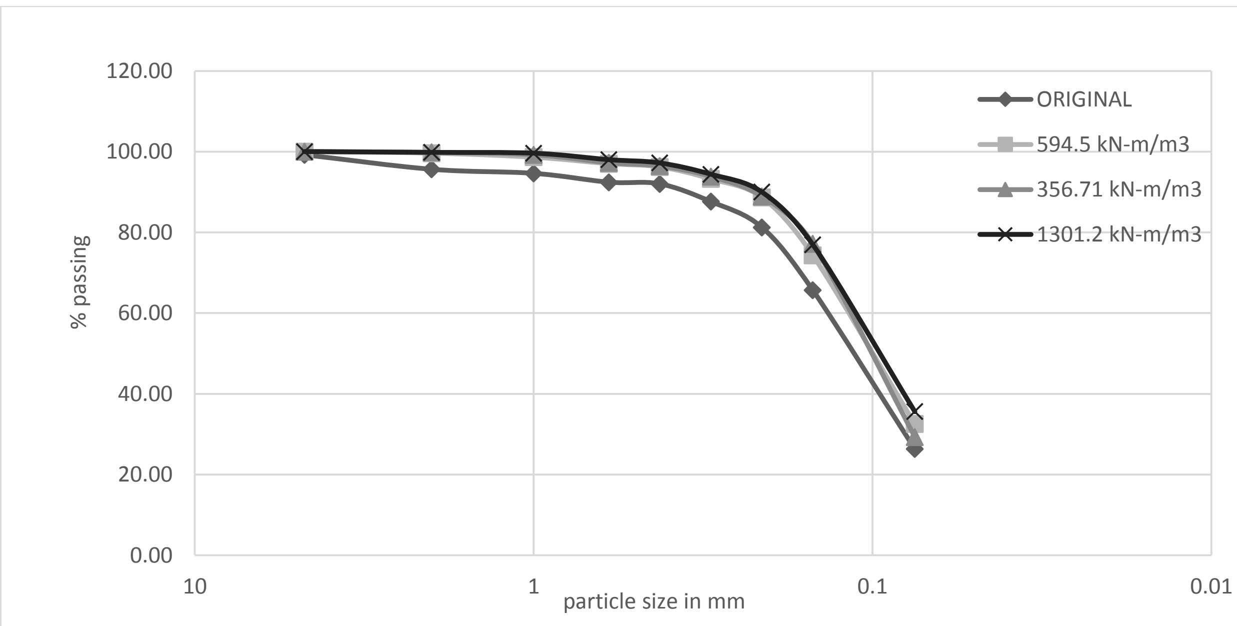

Figure 12: Sieve analysis of bottom ash after applying different compaction energy (Vedanta, Jharsuguda)

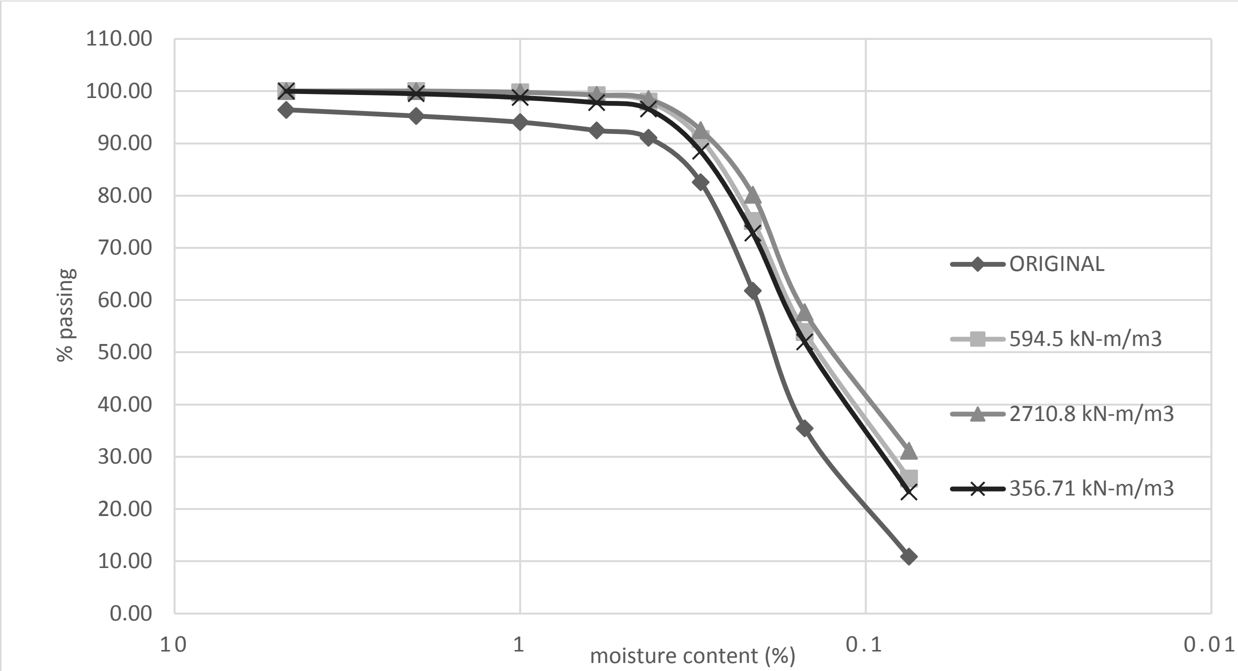

Figure 13: Sieve analysis of bottom ash after applying different compaction energy (NSPCL, Rourkela)

From above graph it can be seen that there is not much change occurred in grain size distribution of bottom ash. As in the laboratory, impact of hammer was applied on the bottom ash for compaction, due to this little change occurred in the particle diameter. It means that when bottom ash is used for field purpose and compaction was done by means of roller which not apply any impact on ash, the change in particle size of bottom ash will be negligible. This conclude that bottom ash can be used as field purpose.

4.4.6 Relationship between compaction energy vs dry density

The effect of compaction energy on dry density has been shown in fig (11), from the curve of compaction energy vs dry density, it can be seen that as compaction energy increases, dry density increases until a critical point reached of dry density. The relationship between dry density and compaction energy is following:

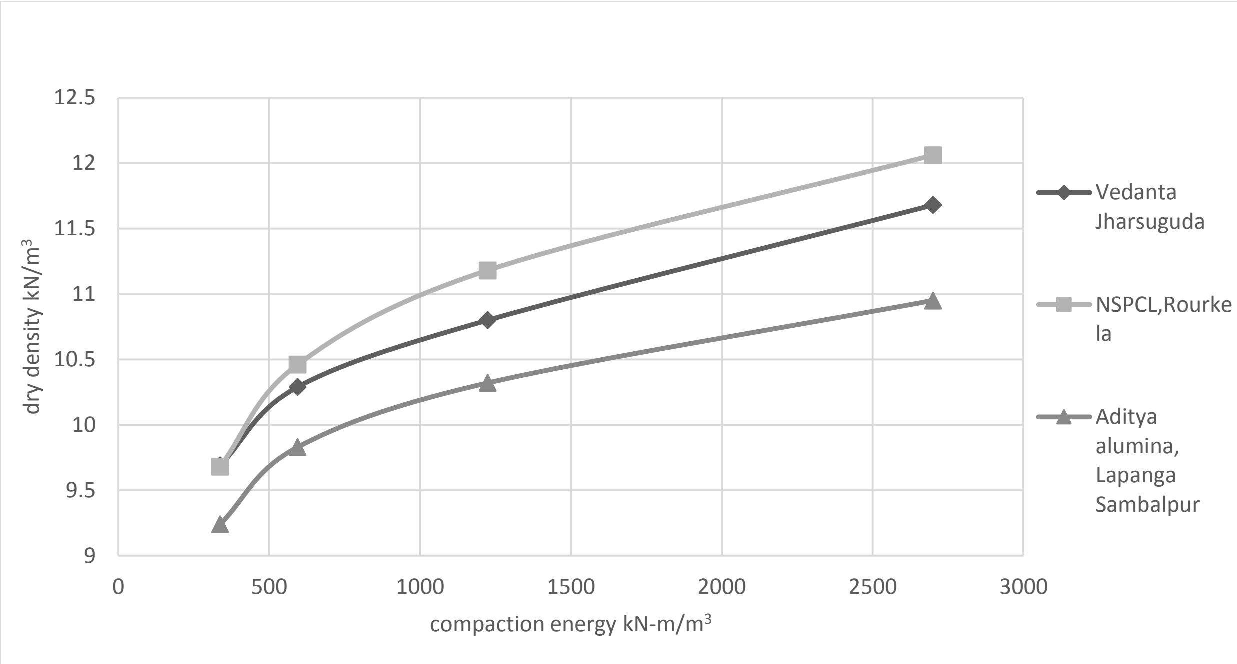

Figure 14: Relationship between compaction energy and dry density of bottom ash collected from (NSPCL (Rourkela), Vedanta (Jharsuguda), Aditya alumina, Lapanga (Sambalpur)

4.4.7Relationship between compaction energy vs moisture content:

Curve has been plotted between compaction energy and moisture content. From the graph it can be seen that as compaction energy increases, moisture content decreases.

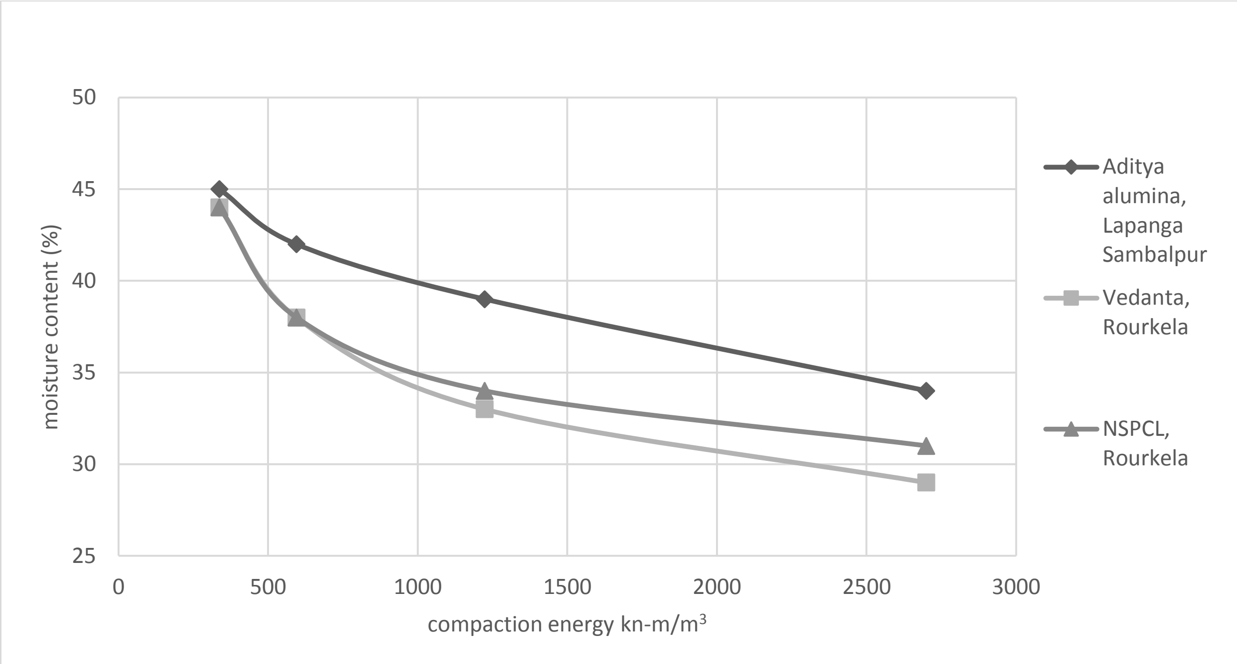

Figure 15: Relationship between compaction energy vs moisture content

4.4.8Influence of specific gravity on dry density:

The relationship between specific gravity and dry density has been shown in fig. According to Bera et al. (2007) that increase in specific gravity, dry density also increases of pond ash. As his work was on pond ash. Here in case of Vedanta, NSPCL Rourkela and Aditya Alumina, Lapanga with increase in specific gravity, dry density decreases. The reason of having low dry density while having high specific gravity, is may be due to poorly graded ash particle. As, well graded ash particle can fill the air voids while compaction, where poorly graded particle cannot, this results lower compaction of ash hence less dry density.

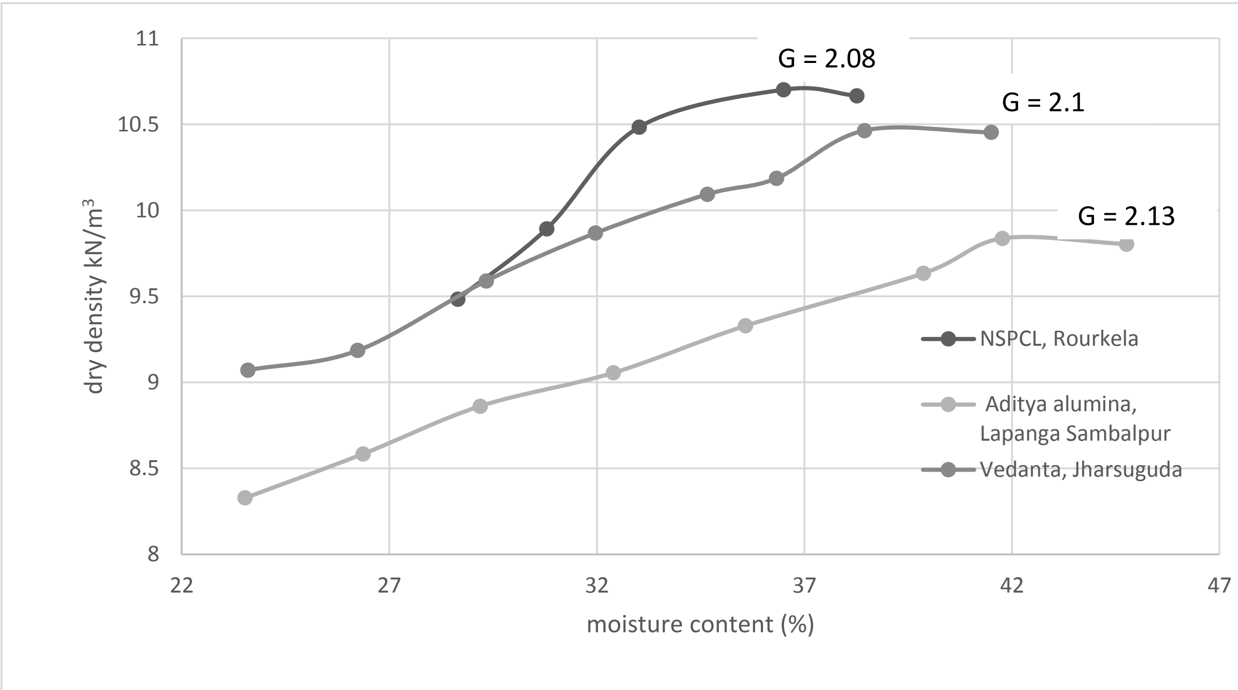

Figure 16: Comparative compaction curve of different specific gravity

4.4.9 Influence of layer thickness on dry density of bottom ash:

During compaction, the ash is compacted in layers to distribute the pressure uniformly. However when layer thickness is increased the distribution of energy applied on it may not be sufficient, this will result lesser compaction of lower part of layer. Therefore, the idea is to see the change in dry density of bottom when thickness of layer is variable.

4.4.10Variation in layer thickness when compaction energy is variable

In this section the layer thickness was changed as well as compaction energy also changed. Here the compaction energy changed as there is no changes was done in number blows but in number of layers. So according to compaction energy equation the energy was changed. The layer thickness was controlled by number of layers compacted in mold and by dividing total height of compaction mold with number of layers used, thickness of layer calculated.

Following curves shows the variation in dry density of bottom ash with the variation in compaction energy and number of layers was given during compaction.

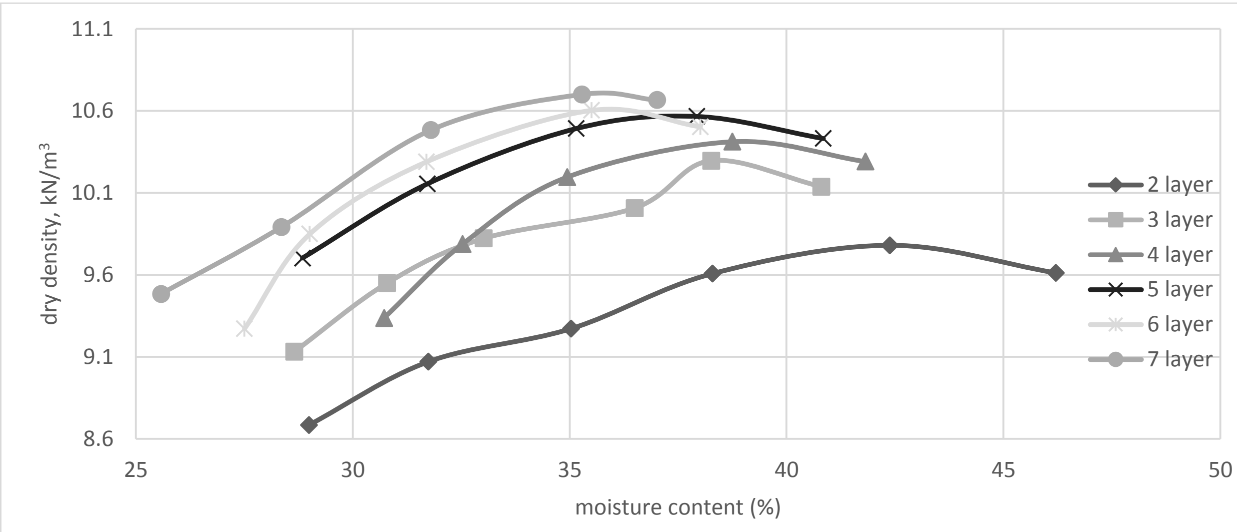

Figure 17: Effect of layer thickness on dry density of bottom ash (Vedanta, Jharsuguda)

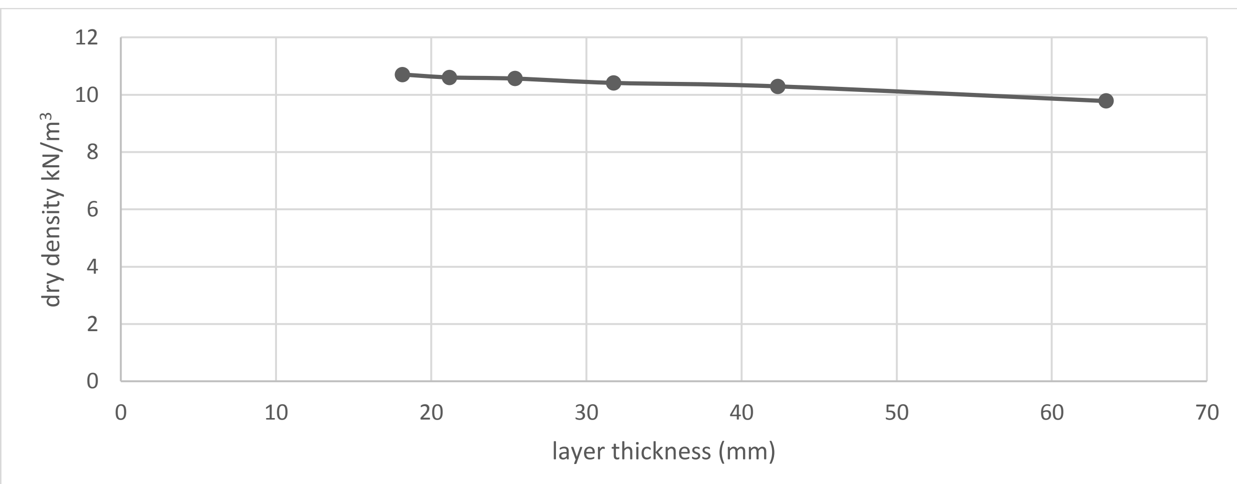

Figure 18: Relationship between layer thickness and dry density of bottom ash (Vedanta, Jharsuguda

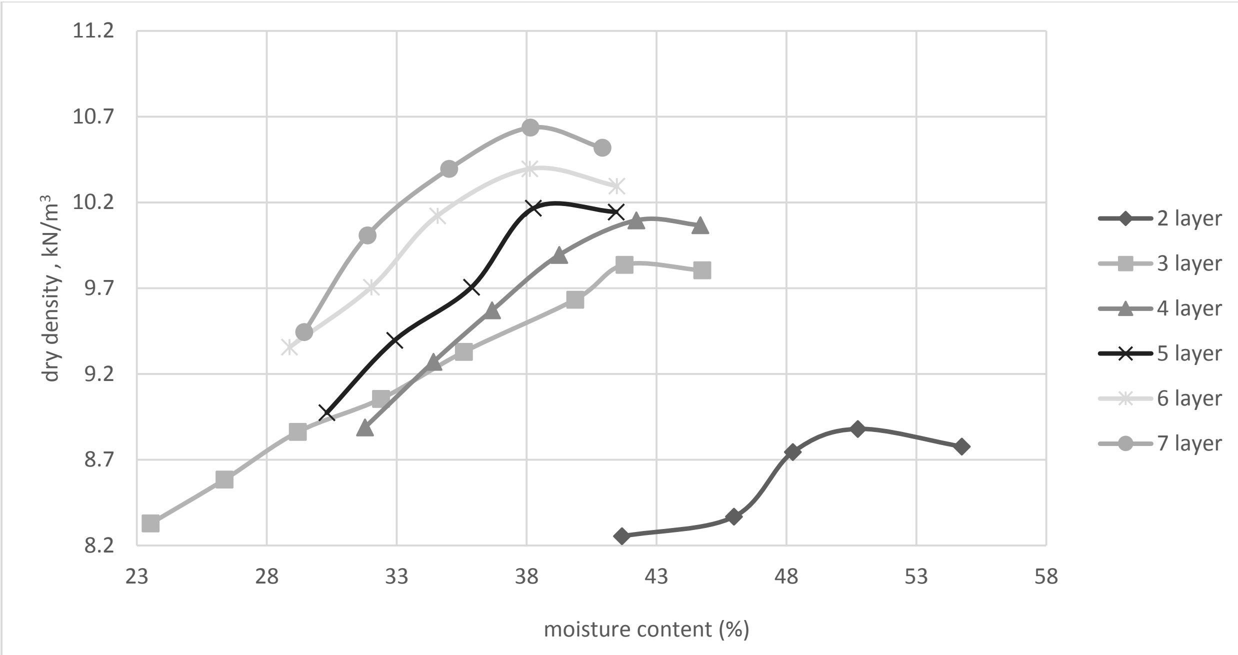

Figure 19: Effect of layer thickness on dry density of bottom ash (Aditya alumina, Lapanga Sambalpur)

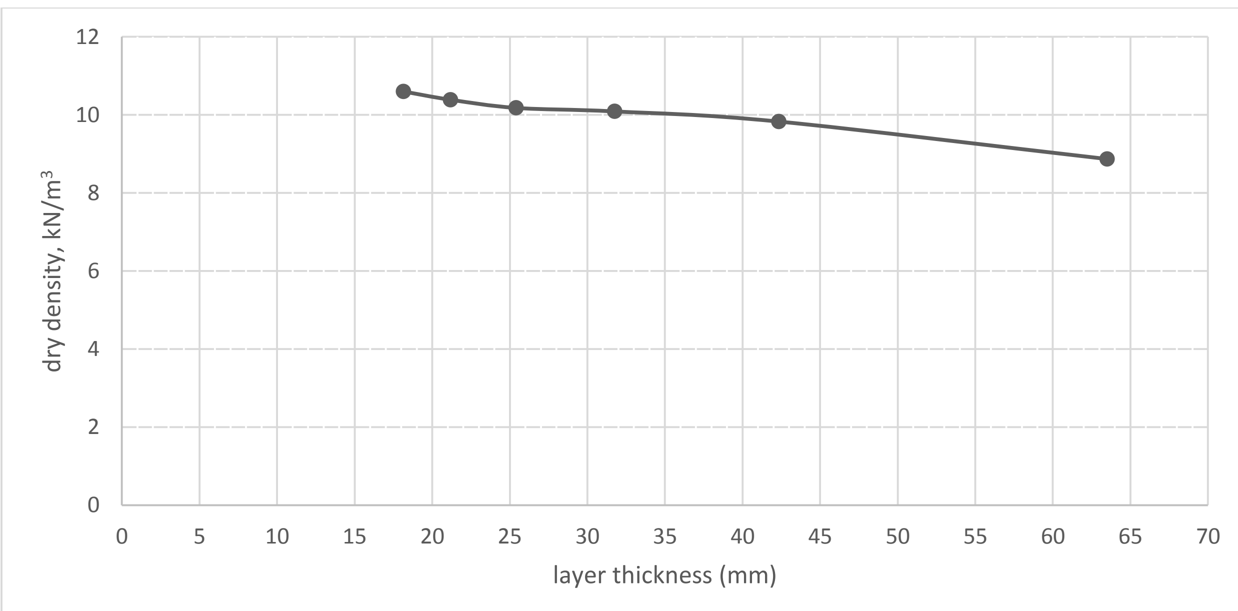

Figure 20: Relationship between layer thickness and dry density of bottom ash (Aditya alumina, Lapanga Sambalpur)

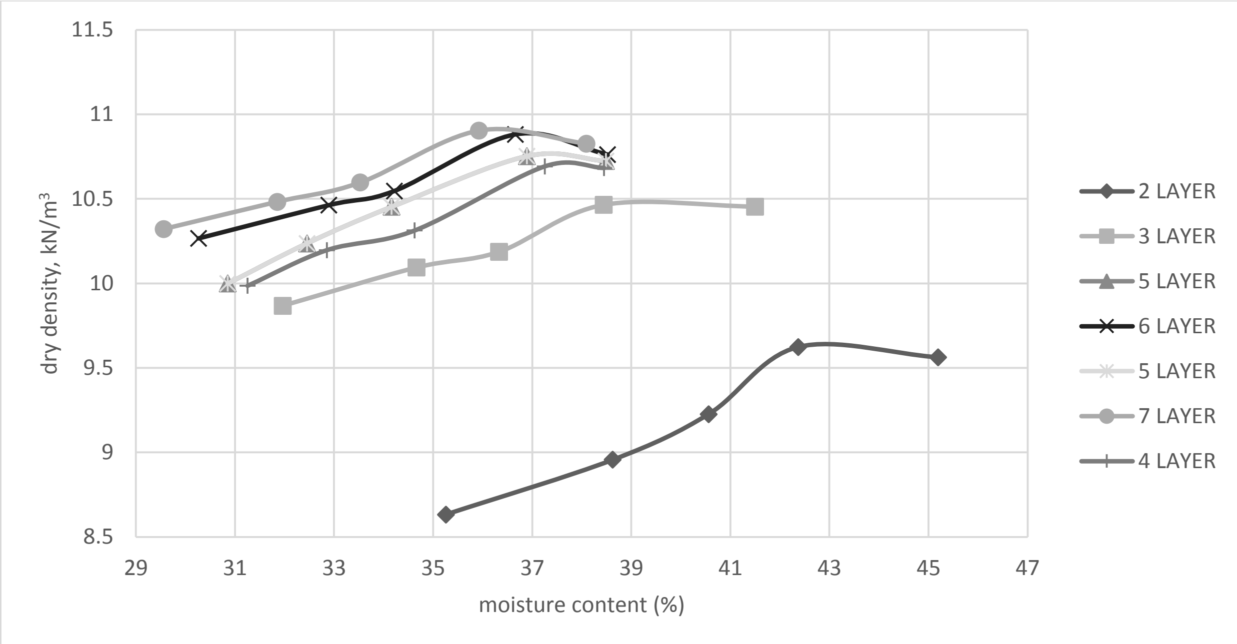

Figure 21: Effect of layer thickness on dry density of bottom ash (NSPCL, Rourkela)

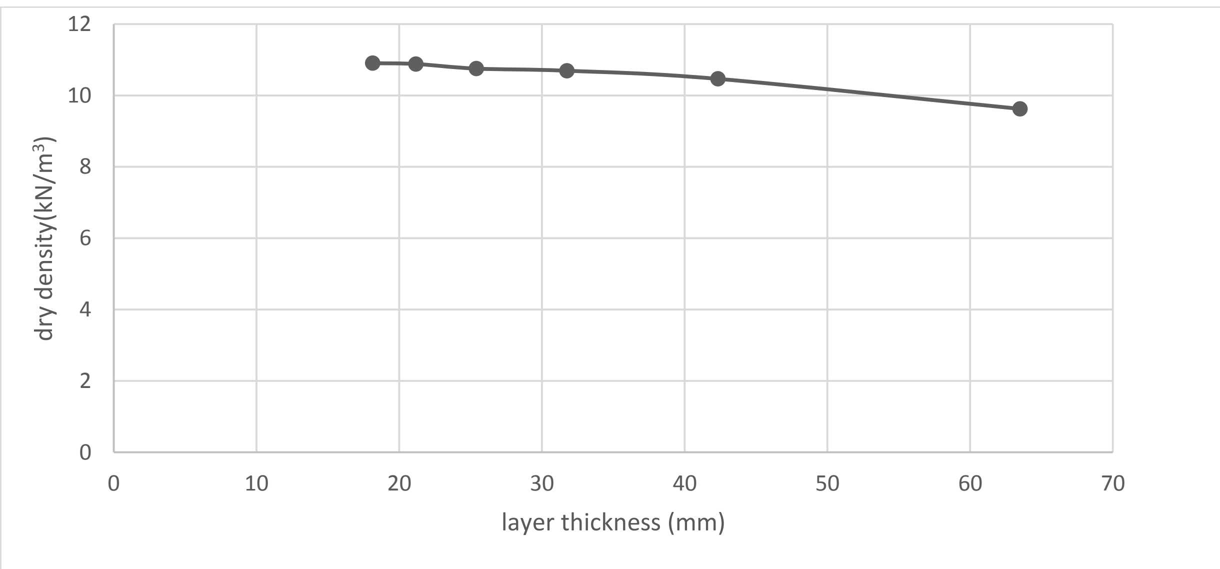

Figure 22: Relationship between layer thickness and dry density of bottom ash (NSPCL, Rourkela)

From the graph between layer thickness and dry density it can be seen that after certain number of layers the curve goes almost parallel to layer thickness axes (x-axes). That means after a certain thickness of layer there will not be much effect on dry density of material used.

4.4.11Variation in layer thickness when compaction energy is constant

The variation in layer thickness was given but compaction energy/unit volume was constant. By changing in number of blows/layer, the compaction energy was kept constant.

The following graph shows the change in dry density keeping imparted energy constant while change in number of layers:

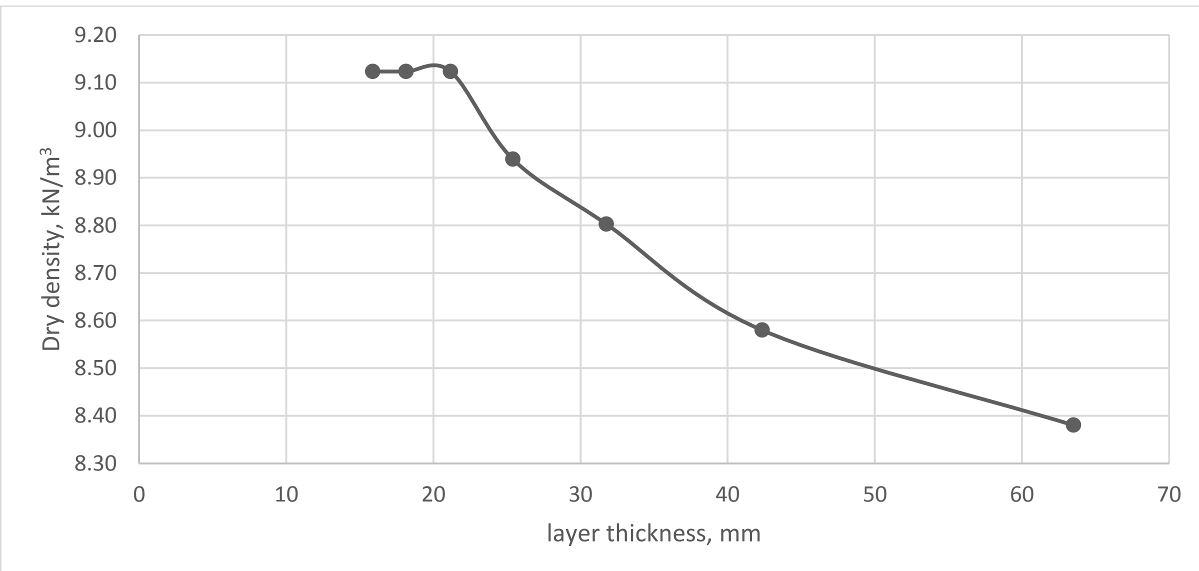

Figure 23 Relationship between layer thickness and dry density of bottom ash (Aditya Alumina, Lapanga Sambalpur)

From fig. 23 it can be seen that after a certain layer thickness there is negligible change occurred in dry density of bottom ash. On the basis of experiments the limiting layer thickness was found to be 18.14 mm in proctor mold at OMCproc, keeping compaction energy constant by adjusting the number of blows per layer. To accomplish optimum layer thickness of compacted bottom ash in the field, illustration of trial stretch should be done. The same behavior occurred for other two bottom ashes.

4.4.12Compaction in CBR mold

Compaction in CBR mold was also done in order to give variation in mold area to see the effect of mold area on dry density of bottom ash. The diameter of mold was 15.1 cm and height was 12.7 cm and volume of the mold 2274.299 cm^3.

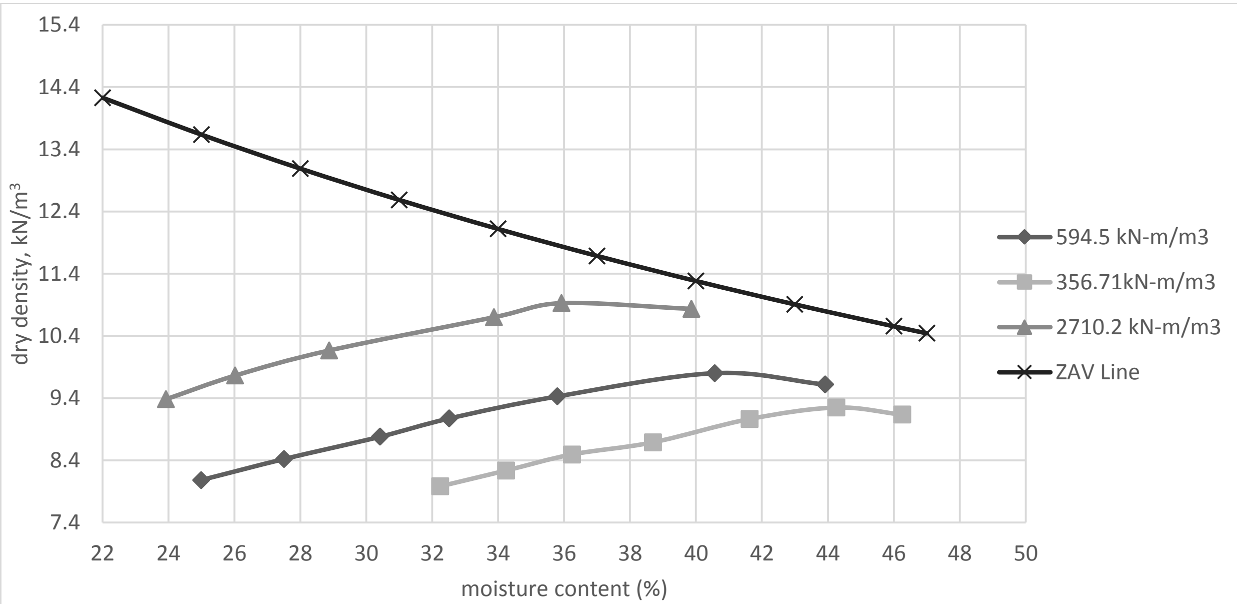

Figure 24: Compaction done in CBR mold at different compaction energy (Aditya alumina, Lapanga Sambalpur).

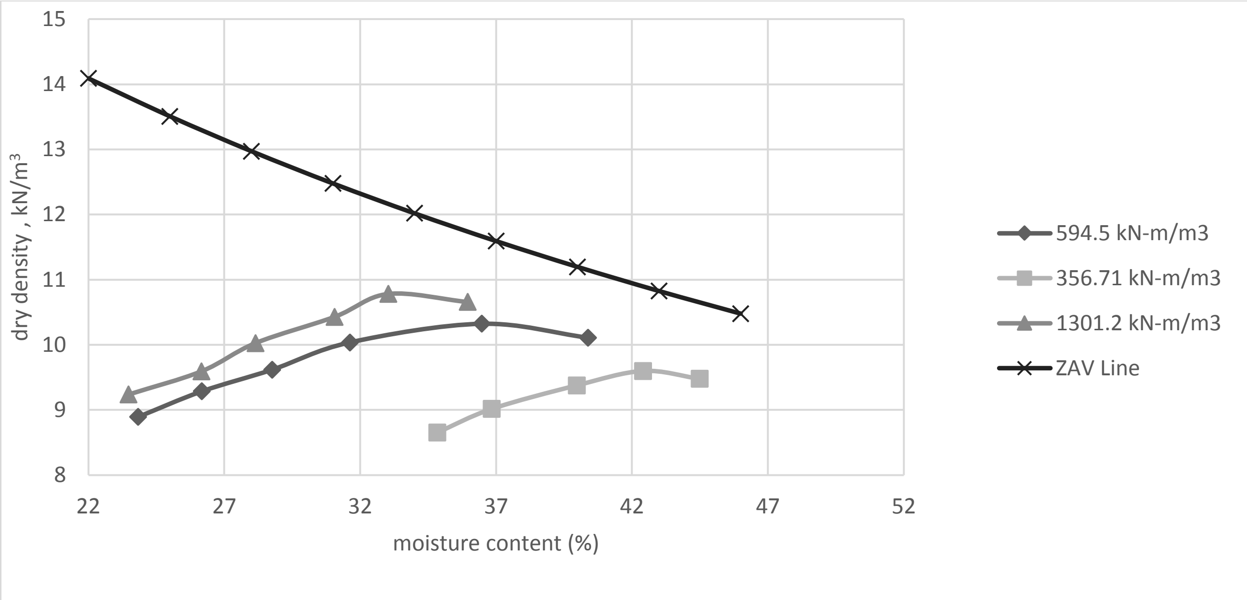

Figure 25: Compaction done in CBR mold at different compaction energy (Vedanta, Jharsuguda).

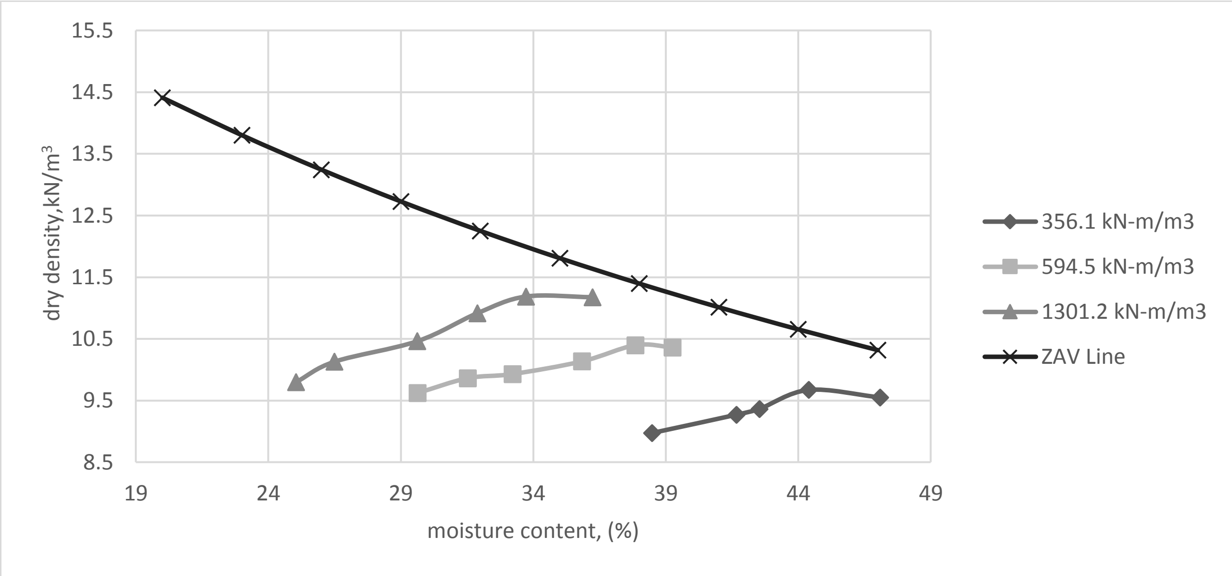

Figure 26: Compaction done in CBR mold at different compaction energy (NSPCL, Rourkela).

4.4.13 Effect of mold area on dry density of bottom ash

4.4.13.1 Comparison of dry density determined in two different molds

Comparative curves have been plotted of dry densities determined in two different molds. The molds ware used are: proctor mold, CBR mold. The idea, to change in mold area to decrease the area of confinement for better arrangement of particles, which may be affect the dry density while keeping the compaction energy constant per unit volume. But as we can see from the graph that there is almost negligible change occurred in dry density and moisture content of bottom ash after increasing the mold area from 78.535 to 179.01 cm^2.

The dry densities of bottom ash in two different mold for different compaction energies have been given in Fig no.: 27, 28, and 29.

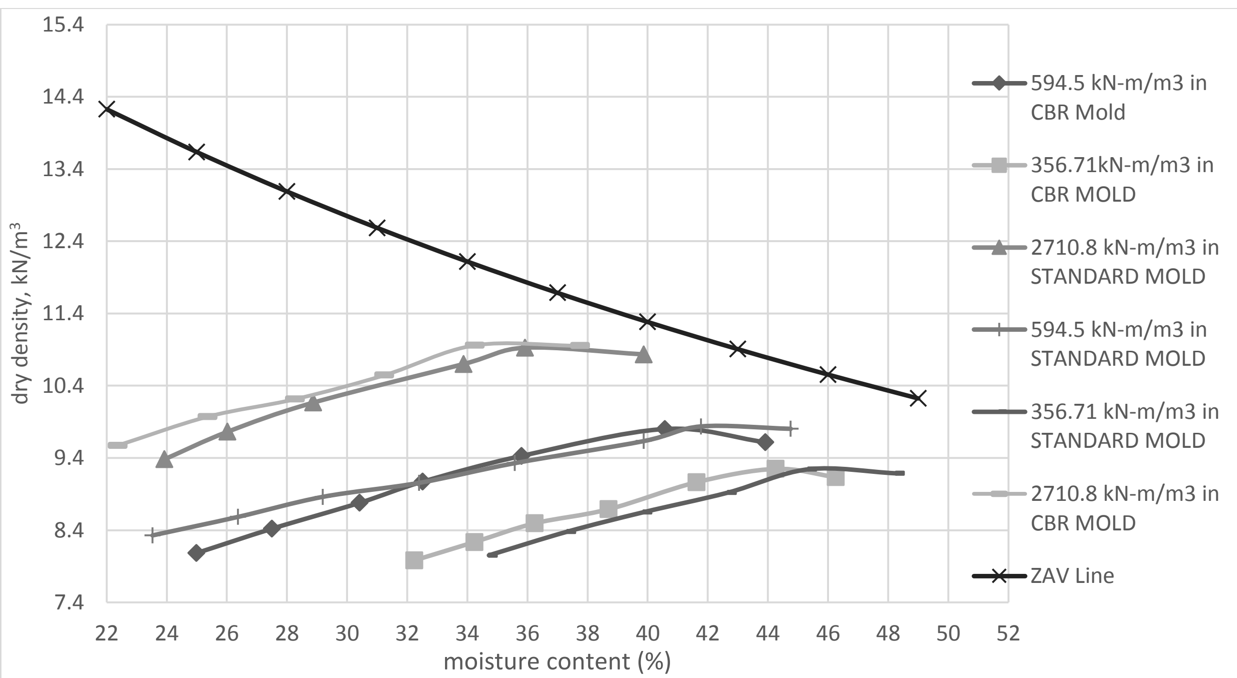

Figure 27: Effect of mold area on dry density of bottom ash (Aditya alumina, Lapanga Sambalpur)

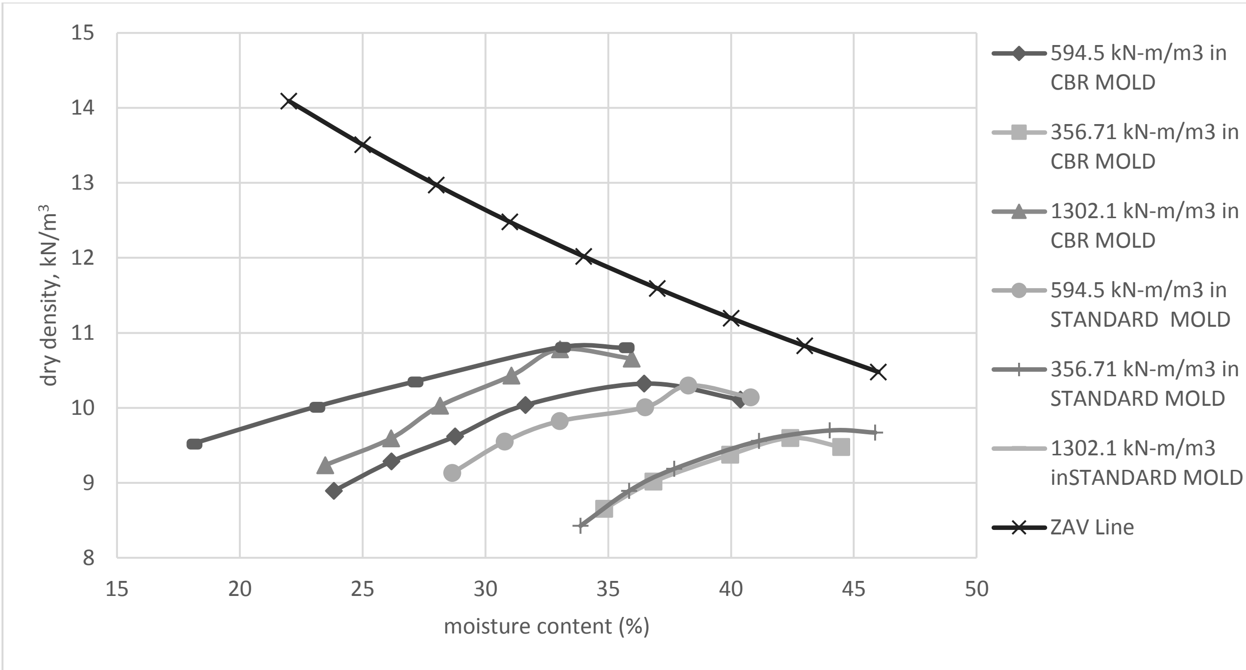

Figure 28: Effect of mold area on dry density of bottom ash (Vedanta, Jharsuguda)

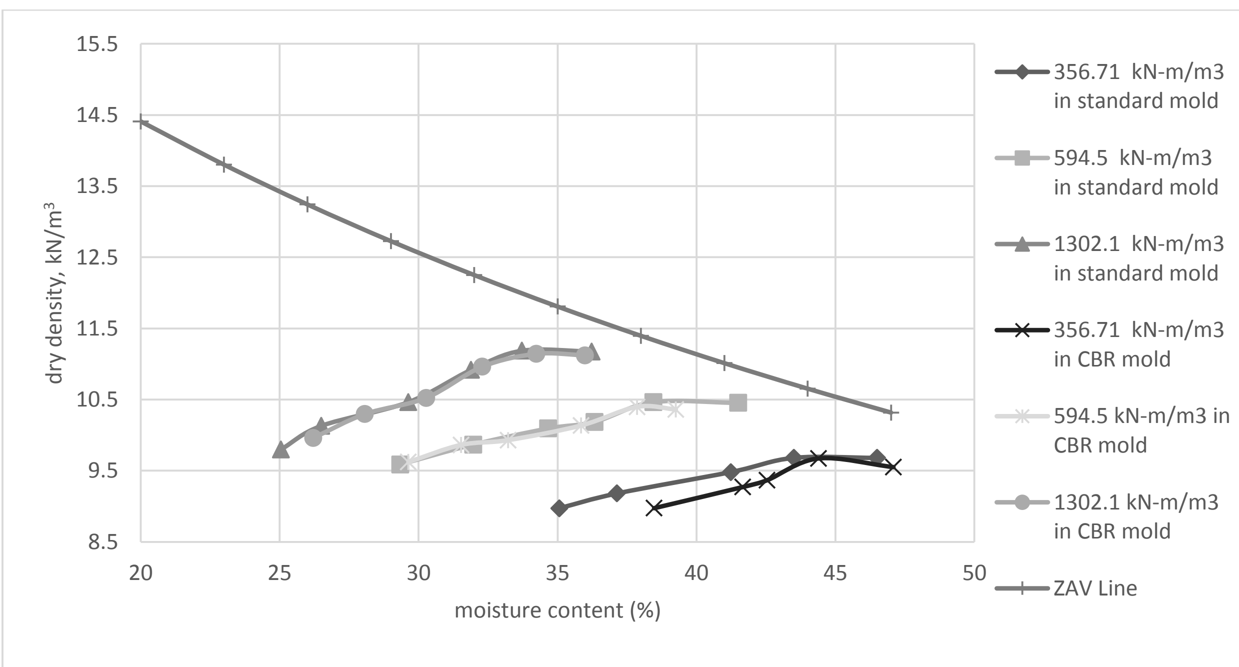

Figure 29: Effect of mold area on dry density of bottom ash (NSPCL, Rourkela)

4.4.14 Empirical model

In this study it has been seen that there is linear relationship between compaction energy and dry density of bottom ash. Therefore as compaction energy increases there is increment in dry density occurred with decrement in moisture content. Thus it can be concluded that there is a linear relationship exists between compaction energy, dry density and moisture content of bottom ash. However after observing all these factors, checking their linearity to each other, an empirical model has been developed to find out the dry density of bottom ash in terms of compaction energy, water content, and specific gravity. To establish the present model, multiple regression analysis was done, which is based on 55 data points. The empirical model is shown below,

$$\acute{y}_d = 0.000424 \times (E) - 0.084936 \times w - 9.456652 \times G + 33.055442 \qquad \text{(i)}$$

Where $\acute{y}_d$ = predicted value of dry density in kN/m^3

E = compaction energy in $kN\text{-}m/m^3$

w = moisture content and

G = specific gravity

The value of correlation coefficient (R^2) is 0.952 and standard error was 0.19 occurred. Fig A shows the plot between observed and predicted dry density of 55 data points with less than 5% error or variation. The curve between observed dry density and predicted dry density of bottom ash has been shown in fig 30:

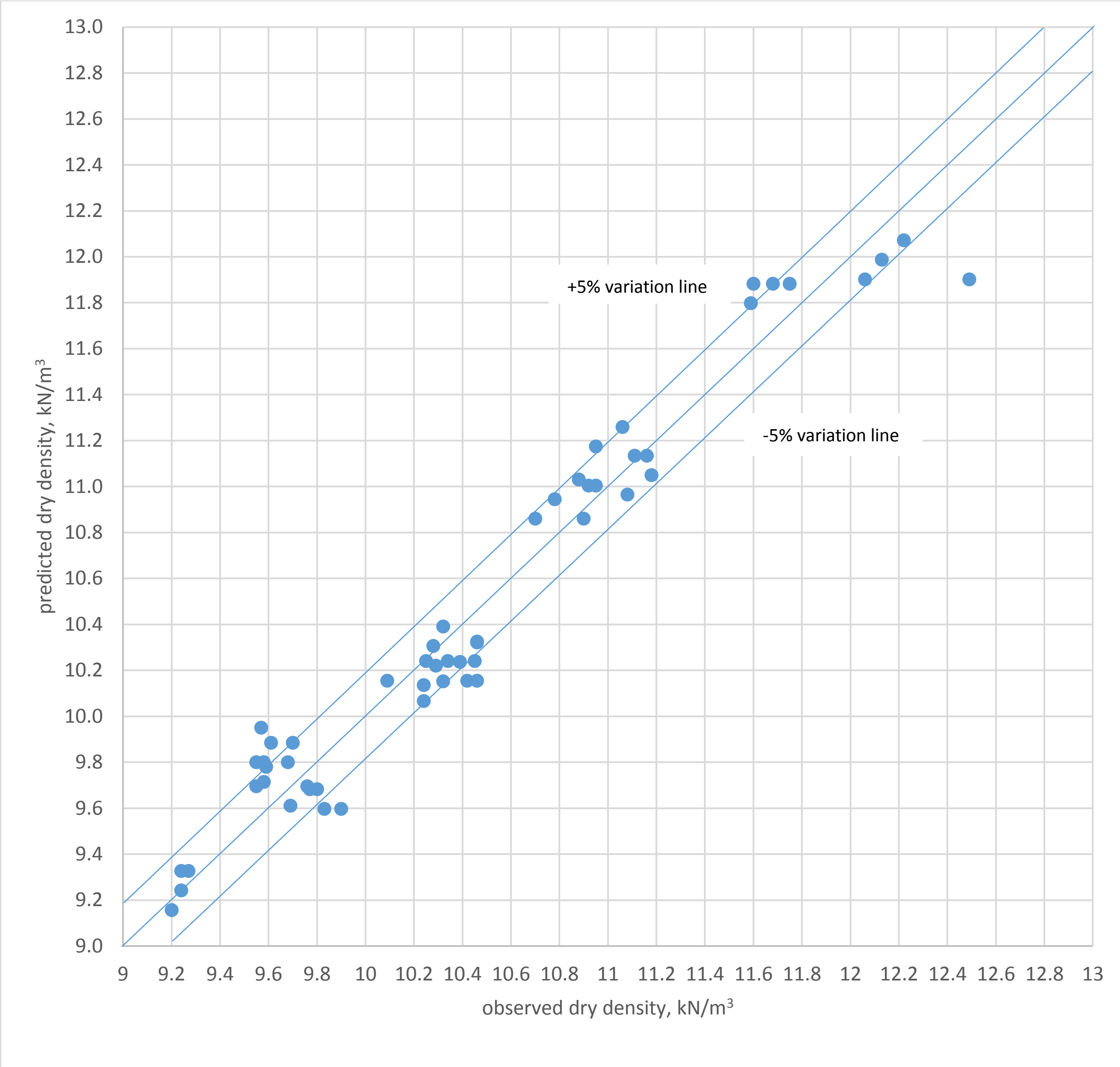

Figure 30: Observed dry density vs predicted dry density of bottom ash from Eq. (i)

Therefore, to validate the empirical model for determination of dry density, this has been tested using 18 more data points which are not used for analysis of model. And the % error was occurred 0.14 to 4.04%, which is an acceptable value.

This empirical model can be used for preliminary estimation of moisture content and compaction energy of bottom ash in the field. And specific gravity can be determined in laboratory in order to use in the model to calculate the dry density of bottom ash. But this model can give good results for the bottom ash which have range of specific gravity between 2.08-2.13 and compaction energy between 356.71-2710.8 kN-m/m^3. Beyond this range of specific gravity and compaction energy, the results of this model should be checked before by doing certain experiments according to the site conditions.

Table 6: Comparison of Predicted Dry Density (Using Additional Data not Used in Developing the Model) from Eq. (i) and Corresponding observed Dry Density

Reference value	E,	w	Dry densities		
	kN-m/m^3	(%)	G	Predicted	Observed
Present work	396.35	51	2.13	8.75	8.87
Present work	594.53	41	2.13	9.68	9.83
Present work	792.71	42	2.13	9.68	10.09
Present work	990.88	38	2.13	10.11	10.16
Present work	1189.06	38	2.13	10.19	10.39
Present work	1387.24	38	2.13	10.27	10.63
Present work	2710.80	36	2.13	11.00	10.95
Present work	396.35	42	2.1	9.80	9.78
Present work	594.53	38	2.1	10.22	10.29
Present work	792.71	39	2.1	10.22	10.40
Present work	990.88	38	2.1	10.39	10.56
Present work	1189.06	36	2.1	10.64	10.60
Present work	1387.24	35	2.1	10.81	10.70
Present work	396.35	42	2.08	9.99	9.62
Present work	594.53	38	2.08	10.41	10.46
Present work	792.71	37	2.08	10.58	10.69

CHAPTER 5

CONCLUSION

5.1 Conclusion

In this study bottom ash collected from three different sites, have been used to explore the effect of various factors i.e., moisture content, mold area , compaction energy, specific gravity, layer thickness on dry density of bottom ash. A no. of tests have been performed and results also analyzed. On the basis of results a linear empirical model has been developed in order to calculate dry density of bottom ash in terms compaction energy, moisture content and specific gravity, which can be used during field compaction for a predetermined idea of above parameters and that can be useful. On the basis of above factors, experiments and discussion made, the subsequent conclusion are:

- The variation in compaction energy significantly affects the dry density. With increase in compaction energy from 356.71 to 2710.8 kN-m/m^3, maximum dry density (MDD) increases at the same time optimum moisture content (OMC) decreases.
- As layer thickness decreases the dry density of bottom ash increases up to a certain thickness, the layer thickness is controlled by dividing the height of mold by number of layer. There is high increment occurred in dry density of bottom ash from 2 layer to 3 layer compaction, beyond which there was very less increment occurred in the dry density. On the basis of experiments the limiting layer thickness was found to be 18.14 mm in proctor mold at OMCproc, keeping compaction energy constant by adjusting the number of blows per layer. To accomplish optimum layer thickness of compacted bottom ash in the field, illustration of trial stretch should be done.
- There is almost negligible change occurred in dry density and moisture content of bottom ash after increasing the mold area from 78.535 to 179.01 cm^2. So it ca be concluded that

the effect of area confinement is negligible, so dry density determined in laboratory can be used in the field.

- The variation in the maximum dry density and optimum moisture content of bottom ash (collected from three different sites) as per Standard proctor compaction energy is 9.77 - 10.46 kN/m^3 and 37-42%, respectively.
- An empirical model has been developed from 55 data points, using multiple regression analysis for calculating the dry density of bottom ash in terms of compaction energy, moisture content, and specific gravity. The model can be used for predetermined estimation of compaction energy and dry density of bottom ash.
- This empirical model is based on experimental data within range compaction energy 356.71 to 2710.8 $kN\text{-}m/m^3$. Beyond these range experiments should be done in order to check the model.

Future scope

The present study is based on bottom ash collected from three different sites. Based on experiments an empirical model has been developed. But the model is limited to a narrow range of geotechnical parameter of bottom ash. The study would be more extensive if bottom ash collected from more no. of sites in order to cover a wide range of dry density, moisture content, specific gravity and other parameters. As properties of ash depends on source of coal and coal burning temperature in furnace, so there is high variation will be there in the geotechnical properties of ash.

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