TO STUDY OF ELECTRICAL RESISTIVITY OF FLY ASH COMPOSITE

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***Abstract*:**Fly ash is gaining importance as a resourceful and commercial material which has market value. The fly ash is the residual waste which is obtained as a by-product after combustion of pulverised coal in thermal power station. The fly ash can be reused, recycled and can be compounded with suitable inorganic chemicals to get value added product. It can be converted into hard and strong tiles and many more value added products hence fly ash has got prime importance in waste management. The present paper deals with the study of electrical properties and electrical resistivity of alkali activated fly ash composite. These fly ash composites have very good compressive strength and can be used as tiles or other building materials. The tiles were prepared by compounding fly ash, lime and sodium hydroxide. Electrical resistivity and other electrical properties are also studied along with temperature and frequency. The correlation also tries for best fitting application. The measurements of electrical resistivity over a wide range of temperatures as per IEEE standards. Empirical relations developed by Bickelhaupt, which are based on the chemical composition of fly ash for calculating the electrical resistivity, which are used to calculate the theoretical value for given experimental conditions.

Keywords: Electrical resistivity, waste management,compressive strength.

I.INTRODUCTION

In India, main source of electrical energy is coal based thermal power plants which contributes 53 % share of total electrical power produced [1,2]. The major problems faced by coal based thermal power plants are the handling and disposal of by-product that is fly ash. This is because of the huge quantity of fly ash produced. The amount of fly ash generated in India is 130 million ton per year [3]. The fly ash disposal problem has assumed such an important issue in the India that the Ministry of Environment and Forests (MoEF) issued a regulation on 14 September 1999 specifying normative levels for progressive utilization of fly ash. It is mandatory for the coal based thermal power plants to utilize 100% of the fly ash produced in a stipulated time horizon [4, 5]. According to Central Electricity Authority (CEA) Report India has achieved only 63.28% of the target in terms of fly ash Percentage Utilization in the year 2016-17 [6]. Hence it has decided to work on the utilisation of fly ash. The utilisation of fly ash is itself a big problem. The fly ash generated by the power stations is transported to the ash pond which takes a large quantity of fertile land for dumping [7]. A huge amount of water is required for transporting the fly ash. The demand and requirement emphasis on application of Fly ash in road embankments, filler, building materials, bricks, in agriculture, in paint industry and many more. The effective use of fly ash it is decided to make an alkali activated fly ash composites which can be converted into some useful in civil construction using these materials such as fillers, tiles etc. with good compressive strength [8]. On the basis of %CaO present in fly ash, it is classified into two categories those are Class F and Class C fly ash, in view amount of calcium, silica, alumina, and iron content, fly ash compound consist silicon dioxide (SiO2), present in amorphous shape, smooth, crystalline, having sharp pointed crystals may be hazardous, aluminium oxide (Al_2O_3) and iron oxide (Fe_2O_3). Fly ash also contains environmental toxins in varying amounts, including barium, the typical values are given asbarium (685 mg/Kg); strontium (726mg/Kg); chromium (153mg/Kg); arsenic (69 mg/Kg); beryllium (9 mg/Kg); boron (311 mg/Kg); cadmium (5mg/Kg); cobalt (41mg/Kg); copper (112 mg/Kg); lead (88mg/Kg); manganese (250 mg/Kg); nickel (70mg/Kg); selenium (7mg/Kg); thallium (6mg/Kg); vanadium (252 mg/Kg); and zinc (161 mg/Kg) [9,10]. The pozzolanic property is observed in class F of fly ash with the glassy silica and alumina. For producing this property it required to make a compound by mixing a cementing agent likes quick lime or hydrated lime with some water. The addition of a chemical activator such as sodium silicate, also known as water glass, to a Class F ash can lead to the formation of a geopolymer [11-14]. The fly ash sample is collected from Khaperkheda Thermal Power plant, Nagpur, which is having energy conversion efficiency about 83%. This means the less amount of destructive elements are present in residue and less acidic resistive. The detail component constitution with percent accompanying of fly ash is shown in Table 1. Fly ash is fine silica content powder with other element as SiO_2, Al_2O_3 Fe_2O_3, the particles of which are generally spherical in shape from 0.5 to 100 μm in size [15]. This can be recycling of waste product as environmental remediation obtained from thermoelectric power plant. Electrical conductivity and other electrical parameters are needed to study along with thermal behaviour to develop the material application for frequency base working environment. Thermal conductivity is the heat carrying capacity of the materials which is elementary characteristic of material that conducts heat [16].

Table 1: Basic composition of the fly ash

Sn	Compositions	% amount
1	Silica	55.81
2	Aluminium Oxide	25.41
3	Iron Oxide	9.35
4	Titanium Oxide	0.28
5	Manganese oxide	0.21
6	Magnesium oxide	1.18
7	Calcium Oxide	1.28
8	Sodium oxide	1.28
9	Potassium oxide	0.96
10	Loss on ignition	1.82

This paper elaborates the application of fly ash for development of tiles for the home base and industrial based application where the temperature and electrical environment are at higher side. The application of fly ash depends on the electrical properties as storage of charge and thermal properties as temperature dependency of the material [8]. The fly ash material in doped form developed some measurable electrical parameter on which the application of fly ash is design. This paper is one of the trial method reported with the reference to the electrical and thermal properties of fly ash composites toward the development as application in civil and household applications. Some of electrical parameters are studied below. Electrostatic Precipitator ESP depends largely on the properties of coal burned, fly ash generated and resistivity measurement Measurements were made on ascending and descending mode of temperatures for different amount of concentration and doping agent [17, 19-21]. The observations are there are significant changes in resistivity during ascending mode between actual sample and doped sample and these changes are more pronounced at lower temperatures (50^0C), where surface conduction dominates through fly ash deposited on the collecting electrodes. There is significant drop in resistivity corresponding to enhanced value of doping activity, velocity, collection efficiency of ESP. One may conclude from these observations that ammonia dosing enhances surface conduction (50^0C), thereby reducing the resistivity. The result of NH_3 dosing improves collection efficiency of ESP and decreases the emission levels. As the temperature is raised to 50^0C, the effect of water is barely observed [17, 19-21].

2.EXPERIMENTAL

2.1 Synthesis technique

A low cost composite using simple methodology was developed; no expensive machinery or equipment is required for processing. The raw materials used are readily available which were utilized in the process. The electrical resistivity, conductivity and other electrical parameters are analysed in three sets of prepared samples. The sample series I composite was prepared by grinding mixing, and heat treatment using sodium hydroxide, lime and fly ash in the proportion 1:2:3 by weight proportion in order to yield a homogenous mixture of geo-polymer paste. After homogeneous mixing in pestle mortal, alkali activated fly ash circular discs as shown in figure 1, of fixed diameter (d) were prepared from the above composition by applying varying pressure in hydraulic press (6 ton to 10 Ton). Thus five samples series I are prepared (F-6 to F-10). These discs were first dried for 2 days, and then cured in water for 14 days, again dried for 2 days then heated at 70 degree centigrade for 15 minutes to get experimental sample of fly ash composite. Sample series II (T-6 to T-10) is prepared for temperature variation test with same preparation processes.

Figure 1. Synthesized experimental samples (F-6 to F-10)

Table 2 Compositional concentration of fly ash composite

Sn	Sample	pressure (Ton)	NaOH (gm)	$CaCO_3$ (gm)	Fly Ash (gm)	Thickness (mm)	diameter (mm)
1	F-6	6	0.25	0.5	0.75	4.6	16.1
2	F-7	7	0.25	0.5	0.75	5.1	15.7
3	F-8	8	0.25	0.5	0.75	4.8	15.8
4	F-9	9	0.25	0.5	0.75	5.2	15.8
5	F-10	10	0.25	0.5	0.75	4.8	16.1

The diameter and thickness are noted, other test of the composite is made by same composition by compounding sodium hydroxide and lime with fly ash in 1:2:3 proportions. The circular disc is prepared with thickness of 4.3 mm and diameter in range of 16-17 mm. These discs were dried for 2 days and then kept in water for curing for 14 days, then heated at constant temperature of 70^0C [17,18]. A typical composition of fly ash for sample series F-6 to F-10 is shown in table 2 by applying pressure by pressing machine.

2.2 Characterization technique

The investigation for the composition of fly ash and its residue after making composite was carried out at Anacon Lab, Nagpur with standard procedure of preparation. The electrical study are carried out with the Wayanker make (model no B-6500B) impedance analyzer, this provides 17 different electrical parameters.

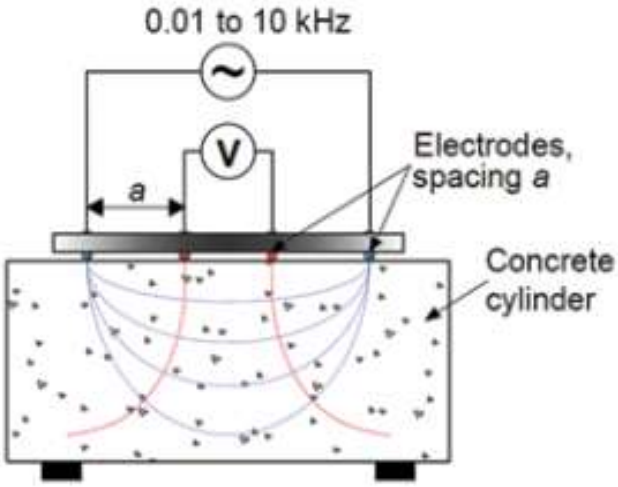

Figure 2. Principle working diagram four probe method for electrical measurement

The resonance parameter of sample also tested using the Impedance LCR Meter to find out the L, C, and R value which has close relevance with the empirical relationship calculated [17]. The surface electrical resistivity of concrete is measured using four electrodes method based instrument Waynker B6500 model impedance analyser. One widely accepted setup is having four probes, where the four electrodes are located in a straight line and equally spaced see figure 2. The two inner electrodes measure the electrical potential V created when the exterior electrodes apply an AC current I to the concrete [16].

3. RESULTS AND DISCUSSIONS :

The samples of fly ash composite are synthesised, cured and kept at 70^0C temperature, are done as per the prescribed method. The sample are well sintered at higher tempt up to 300^0C and sample are tested for mechanical, electrical and thermal behaviour. The sample shows different characteristics in this report thermal and frequency depended properties of the sample [8]. The result shows the extinct characteristic with frequency. The initially frequency gives full charge value of capacitance where frequency increase; there is decreases in capacitance developed in the material between 7.1984 to 5.4152pF. Also the decay starts at the base frequency of AC at 50 KHz and martial activity control the instant charge deliverability, this impact retain till the multiple harmonic level of AC field which state the suitability of martial application in high energy, high frequency electrical environment for reducing the static charge storage and retention property. The material capacitance increases with the increases in the concentration of carbon compound, the strong application orientation of material in the electrical vibration suppression [12]. From figures it is noted that the set of minimum charge retain at frequency are correlated, but they are not one to one better correlation with subsequent setting of AC frequency. The significance of water content and the capacitance are mixed phase due to surface geometry of the sample and method of preparation of sample. The details of capacitance are tabulated in table 2 for different concentration of sample prepared at different pressure [22].

3.1 Electrical resistivity (ρ)

The resistance is the opposition offered by a material for flow of electrons, the electrical resistance of an electrical conductor is a measure of the difficulty to pass an electric current through that conductor. It can be correlated to friction in mechanical terminology. The electrons can flow freely through a copper wire, but cannot flow as easily through a steel wire of the same shape and size, and they essentially cannot flow at all through an insulator like plastic regardless of its shape. This different behaviour of flow of electrons offered by copper, steel and plastic is due to their microscopic structure and this property is called as resistivity (ρ) or specific resistance and its unit is ohm-meter (Ω·m). The fly ash sample is prepared with different combinational weigh manner to test the electrical activity of sample [21-22]. The weight concentration and dimensional details of sample prepared is shown in table 2. Electrical resistivity measurement techniques are becoming popular among researchers and scholars for the quality control and durability assessment of fly ash. The adoption of these techniques into standards and guidelines has been rather slow, with only surface electrical resistivity adopted as a test method. Due to a porous microstructure which are interconnected increases permeability and reduced durability in general [14,15]. Thus electrical resistivity has importance in the conductive properties of the microstructure of concrete. In short it can be said that the ability of concrete to withstand the transfer of ions subjected to an electrical field can be termed as electrical resistivity of concrete [16,23-25]. The resistive element of fly ash gives the relationship that with temperature shows the resistance decreases.

Table 3. AC frequency applied vs resistivity for samples

Sn	Frequency (KHz)	Resistivity K-ohm-m Sample F6	Resistivity K-ohm-m Sample F7	Resistivity K-ohm-m Sample F8	Resistivity K-ohm-m Sample F9
1	50	70.4610896	73.6543193	77.15225	82.9948527
2	100	31.3393171	31.6002493	32.9432848	38.0517504
3	150	18.8093671	18.9610882	19.4783124	23.6392648
4	200	12.9059402	12.8495947	13.2979608	16.6507097
5	250	9.42966999	9.59406365	9.66951531	12.5281884
6	300	7.24143112	7.57775753	7.61602732	10.0742979
7	350	5.72410828	6.14828345	6.15640532	8.33802347
8	400	4.70999279	5.13226159	5.07587288	7.02148575
9	450	3.86979981	4.39643025	4.4012128	6.2001085
10	500	3.2169743	3.87380165	3.81049276	5.43146174
11	550	2.78537489	3.39564696	3.34464996	4.81347774
12	600	2.40021208	3.06476927	2.99139451	4.37790036
13	650	2.09804038	2.75258747	2.67393657	4.03506471
14	700	1.87144151	2.49985328	2.4855135	3.746862
15	750	1.63571512	2.31447698	2.23906672	3.42483347
16	800	1.46919617	2.10763392	2.07622227	3.23436186

The effect of temperature and frequency variation follows the similar trend line given in the graph. The frequency based measurement, the molecular activity is decrease which reduces the molecular resistance of sample. The frequency based relationship gives the combination of linear pattern and same trends are followed by other samples too. The molecular activity of sample is reduced due to doping ratio of other dopent [8,26-27].

At room temperature of 35^0C the resistance of sample is up to the 80KΩ due to the environmental characteristics and moisture trapping nature of sample. Also in the sample preparation, it may create certain crack on surface which may trapped the water and other foreign particle available in the environment. The higher resistance at the initial level at lower range of frequency or temperature may be due to the present water molecule and Si-O-O-H Bonding [28].

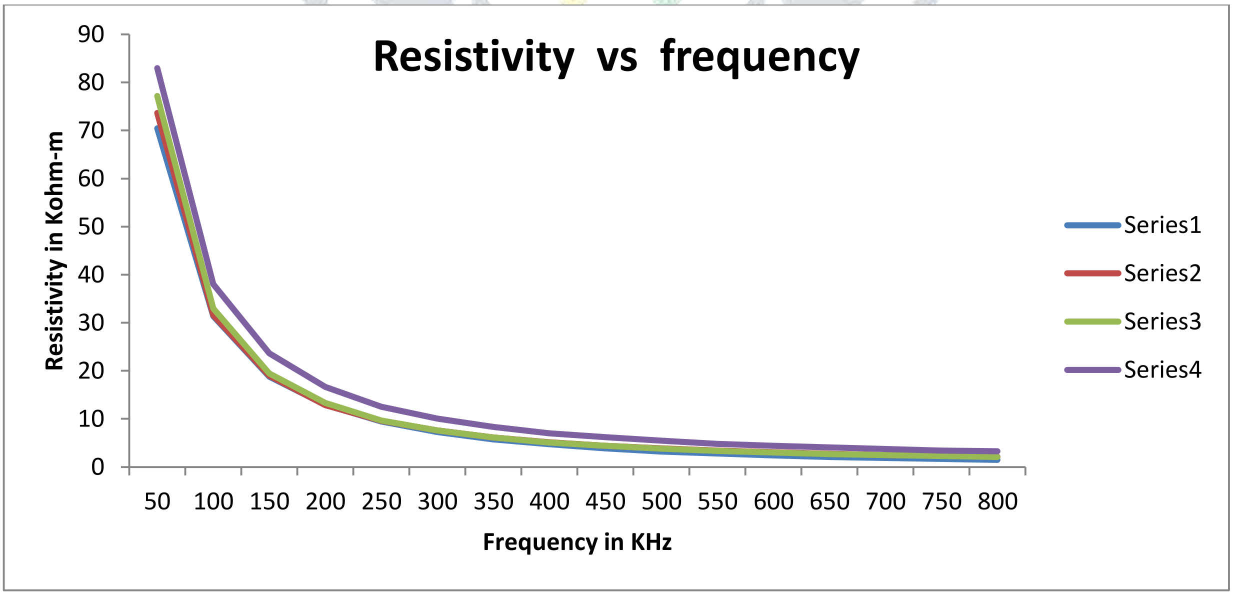

Figure 3. Variation of resistivity with frequency.

The frequency increments create the oscillating nature of sample, creating the intermolecular activity increase and the conductivity decreased as shown in figure 3. This decrease the resistivity of sample up to 10KΩ near to 150-200 KHz. The resistance curve shows linear relation and become in saturated after the 230 KHz giving the resistance value in the range of 4KΩ-7KΩ [29]. The empirical relationship for all type of fly ash and Indian fly ash is implemented on sample and plotted with reference of temperature variation for measurement of sample activity and application orientation of the ash and component controlled using the doping [11,22-25,30].

Table 4. Temperature vs resistivity for samples

Sn	Temperature(C)	Resistivity K-ohm-m S-7	Resistivity K-ohm-m S-8	Resistivity K-ohm-m S-9	Resistivity K-ohm-m S-10
1	30	31.6315	31.1807	26.8403	32.7256
2	40	33.8691	32.4905	28.8773	33.4147
3	50	41.9720	33.8925	36.8167	37.5450
4	70	40.4194	39.1807	37.9747	28.8232
5	90	39.8292	34.3987	38.6804	27.0496
6	100	37.6400	33.7154	38.0062	23.7152
7	120	35.0017	31.4694	36.3716	21.8715
8	140	33.0805	29.6298	34.9566	19.9588
9	160	30.0471	26.5217	32.5388	16.5114
10	170	26.4874	24.9707	30.9992	16.7733
11	180	25.9288	21.7475	30.1689	15.7382
12	190	23.7559	20.1319	29.6507	15.8012
13	200	23.2939	20.2064	24.4233	15.9128

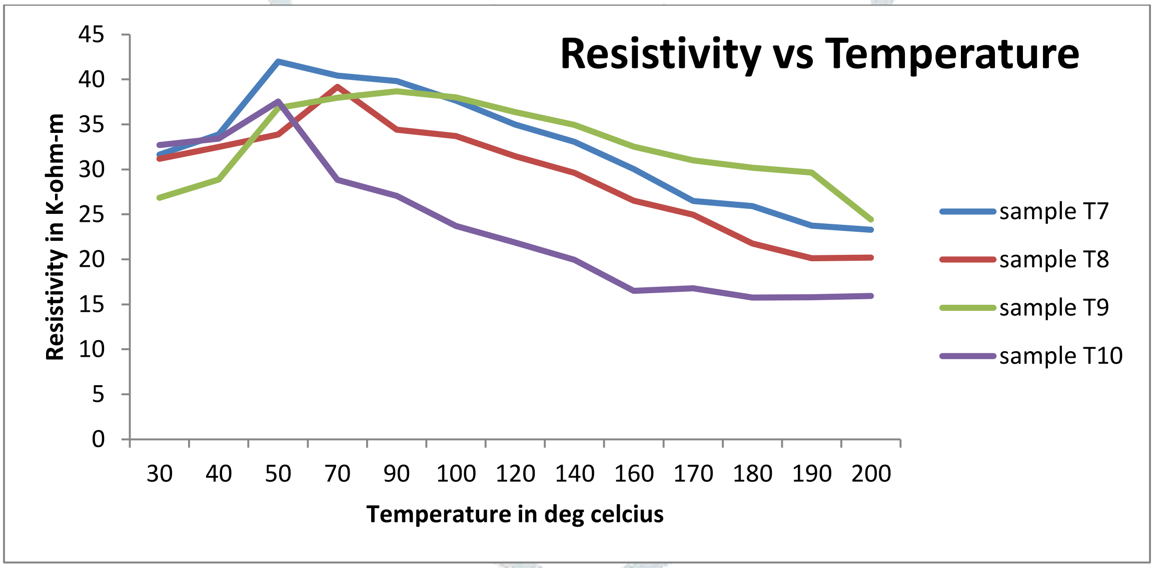

Figure 4. Electrical resistivity with temperature.

Fly ash samples were prepares with the bare sample received from the local power station salt was added to coal mass in such a manner as to increase the sodium oxide content of fly ash by 0.5% [19]. Based on the experimental investigations, the following observations may be made from figure 4. There is enhanced electric conduction due to increased conduction of sodium concentration both at lower (surface conduction) and higher (volume conduction) temperatures.

3.2 Empirical relations for prediction of fly ash resistivity:

Based on the chemical compositions of fly ash samples, shown in table 1, the electrical resistivity with the correlation has been calculated by using Bickelhaupt model [11]. Bickelhaupt proposed the fly ash resistivity measurement from the results of coal and the fly ash correlations to calculate resistivity and other electrical analysis. The correlation fly ash resistivity in terms of volume resistivity, surface resistivity and adsorbed acid resistivity is function of volume and dimension of the pallet of the sample. The surface, volume and acidic resistivity and tabulated in table 4. The Indian ash system shows the less acidic reactivity and acid volume resistivity. The relation for the Indian ash system is also implement and crosscheck with actual observation [8]. The universal relationship for the fly ash system is implemented as follows:

The volume resistivity is:

$\rho_v = \exp[(-1.8916 \text{ Log}X - 0.9696 \text{ Log}Y + 1.237\text{Log}Z + 3.62876) - (0.069078E) + (9980.58/T)]$…….(1)

Surface resistivity

$\rho_s = \exp[(27.59774 - 2.23334\text{Log}X - 0.069078\text{Log}W - (0.069078E) - 0.0007389W(\exp(2303.9/T))]$...(2)

The adsorbed acid resistivity is:

$\rho_a = \exp[(59.09677 - 0.85472CSO - (13049.47/T))-(0.069078E)+(9980.58/T)]$............(3)

The resultant resistivity of sample is measures as

$1/\rho_{vs} = [1/\rho_v + 1/\rho_s + 1/\rho_a]$ .. .. (4)

Table 5. Mathematical modelling of resistivity with different temperature

Sn	Temperature (deg C)	Volume resistivity (K-Ohm-m)	Surface resistivity (K-Ohm-m)	Absorbed acid resistivity (K-Ohm-m)	1/volume resistivity (K-Ohm-m)	1/surface resistivity (K-Ohm-m)	1/absorbed acid resistivity (K-Ohm-m)	Resultant resistivity (K-Ohm-m)
1	50	595.25	354.63	247.46	0.00168	0.00282	0.00404106	117.08417
2	100	945.89	591.6	125.65	0.001057	0.00169	0.00796945	93.9564
3	120	343.28	644.86	330.16	0.00291	0.001551	0.00302883	133.07415
4	150	400.25	698.15	307.91	0.0025	0.001432	0.0032477	139.27462
5	180	88.87	731.55	268381	0.011252	0.001367	3.726E-06	79.219983
6	200	33.54	746.77	90728.6	0.029815	0.001339	1.1022E-05	32.087001
7	250	4.39	771.32	1268278	0.22779	0.001296	7.8847E-07	4.3651405

Bulk resistivity may contain some of surface resistance. Data acquisition can be affected by the thickness of the material, more thin the material, and the more accurate data will be achieved. Surface resistivity also can be influenced by surface treatment. Further investigation is needed in this study [31].

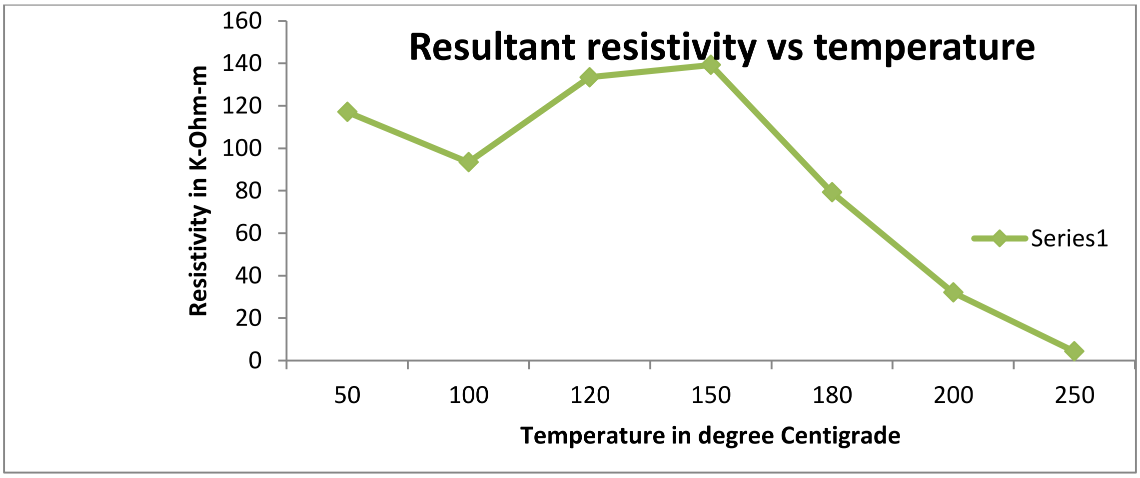

Figure 5. Mathematical modelling

The modelling given by the Bickelhaupt have linear response after attending the maximum resistance but in our case the modelling shows some amount of confilct at the initial level. The variataion of restance is exaclay matac with the observataion but the variataioan in the value F resistsivity is shown twice near to 100ºC the resustance value near to 100 KΩ and at tempreture 150ºC is 140kΩ. The variataioan in the resistance is due to the temperature base active mobility of the material. The composition content the MgO, as one of the elelment incorporate the variation in the resistance with the tempreteure as in figure 5. This shows the fly ash material may be applicabale in harmonic genrtered enevoirnment due to temperature effect. Also this regin may be used in themal power plant to reduec the tempereture based oscillation reduction [32-35].

3.3 Correlation for fly ash resistivity of Indian coal

The Bickelhaupt model in equations can be used to calculate the resultant resistivity for fly ash samples for power plants. Comparison between calculated and experimental fly ash resistivity values for these samples is presented in graph (figure 6). It can be observed that Bickelhaupt model results differ appreciably from experimental values in the lower temperature range (35-250^{0}C). It may be due to significant difference in concentration of elements moisture contents as well as alumina plus silica. The sulphur concentration in coal regulates the adsorbed acid resistivity. Keeping these points in view, the fly ash resistivity for Indian coals was re-calculated in terms of surface and volume conduction. Since the concentration of sulphur is very less in Indian coals, it is worthwhile to assume that very little or zero adsorbed acid conductivity is present [8]. The negligible adsorption of Sulphur oxide, conduction may also be due to formation of glassy alumina-silicate surface that hinders the adsorption of SO on the fly ash surface. The total conduction in fly ash is thus assumed entirely due to surface and volume conduction. The Bickelhaupt expressions for surface and volume resistivity are therefore, modified for the Indian coals. Regression procedure based on the Marquardt-Levenberg algorithm (Least Square Method) is used to find the coefficients of the independent variables of volume and surface resistivity that give the best fit between the proposed correlations and the experimental data. The modified correlation for the volume and surface resistivity is

Correlation for volume resistivity **ρ_v= exp[((-AvLogX – BvLogY+CvLogZ+dv)- ev)E)+(gv/T)]** … …. (5)

Correlation for surface resistivity **ρ_s = exp[As – BsLogx-CsW-dsE- esW(exp(gs/T))]** …… ...... (6)

The resultant resistivity **$1/\rho$ = [$1/\rho_v + 1/\rho_s$]** .... (7)

A - electrode phase area (cm^2),
E - applied electric field (kV/cm),
I - measured current (amperes),
K - potassium percent atomic concentration,
l - ash layer thickness (cm),
T- absolute temperature (K) ,
V- appliedd.c. Potential (volts),
W- moisture in flue Gas (Volume %),
X - Ca + Na, Percent Atomic Concentration,
Y- Fe, Percent Atomic Concentration and
Z - Co + Ca, Percent Atomic Concentration

Table 6. Mathematical modelling of resistivity (for Indian coal)

Sn	**Temperature (deg C)**	**Volume resistivity (K-Ohm-m)**	**Surface resistivity (K-Ohm-m)**	**1/volume resistivity (K-Ohm-m)**	**1/surface resistivity (K-Ohm-m)**	**Resultant resistivity (K-Ohm-m)**
1	50	595.25	354.63	0.00168	0.0028198	222.231763
2	100	945.89	591.6	0.0010572	0.0016903	363.962383
3	120	343.28	644.86	0.0028105	0.0015507	224.640553
4	150	400.25	698.15	0.0025	0.0014324	254.300414
5	180	88.87	731.55	0.0112524	0.001367	79.2433735
6	200	33.54	746.77	0.0298151	0.0013391	32.098353
7	250	4.39	771.32	0.2277904	0.0012965	4.36515553

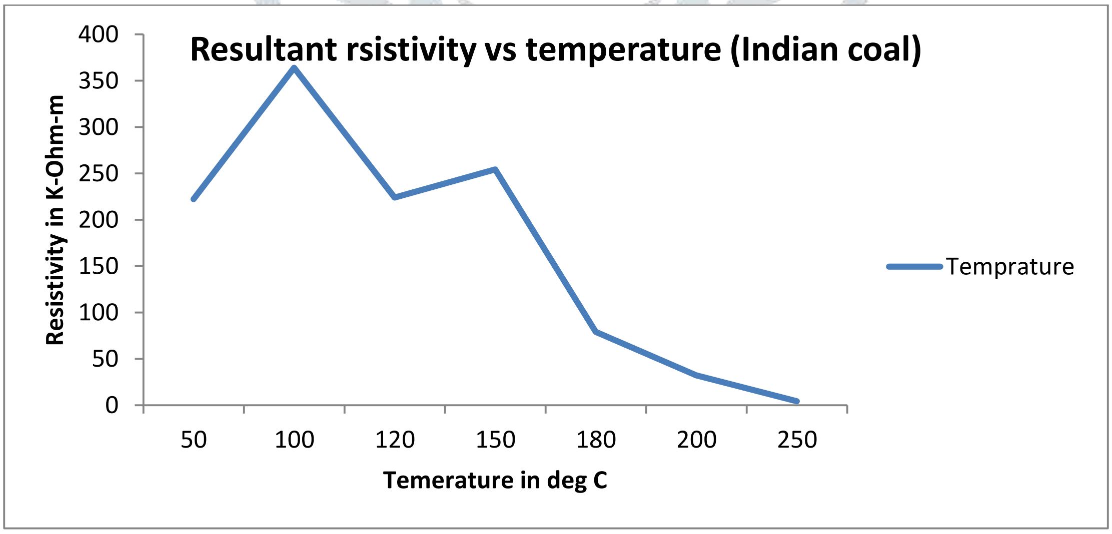

Figure 6. Indian ash modelling (Bickelhaupt)

4. CONCLUSION.

This paper gives the effect of moisture loss in sample will create air voids in the concrete, increasing its resistivity relative to a saturated mix. These voids would also lead to a decrease in the initial formation temperature as the largest saturated pore size would also decrease. The resistivity pattern indicates that at lower frequency the resistivity is found to be in the range of 60 to 80 KΩ-m the resistance at lower frequency shows the presence of moisture element and small room for the damp oscillation up to 200 KHz. The variation of resistivity is also plotted as empirical relation for generalised fly ash. Te frequency relativity is depend on the dimension of the sample but the temperature activity create different application of fly ash resistivity decreased with the increase in Fe, K, Na, and Li contents. by contrast, resistivity increased with increase in percent of Ca and Mg. Si and Al has less effect on fly ash resistivity. Resistivity initially increased first and then decreased with the increase in temperature. Maximum resistivity was observed. Based on the experimental data, a prediction model for fly ash resistivity over a wide range of temperature was established. From the resistivity diagrams the inference can be drawn that typical fly ash samples from different industries can be estimated using chemical composition and temperature data. The sample was exposed to ambient air after removal from the furnaces. This means that the concrete acquire moisture from diffusion to the surface as well as self-desiccation. Self-desiccation is more of a concern in high strength concrete [28]. The change in resistivity with temperature agrees well with the Arrhenius exponential curves presented in the literature at temperatures above 100^0C. For all mixtures and cycles, resistivity increased as temperature decreases. However, there is a distinctive change in resistivity, typically between 65 and 80K, where this curve no longer fits (see Fig.3). The results show that though various mixtures have different temperature-resistivity relationships, they follow similar trends with regards to age and phase transition temperature. This is promising as it shows that electrical resistivity could be used to estimate performance of young concrete mixtures at different temperatures. The further work can be carried to investigate the response of mixtures with other supplementary cementitious materials such as fly ash, silica fume and mixtures. From these study it can be better understand how the resistivity and temperature have relationship, particularly the effect on the phase transition temperatures.

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