LABORATORY TRIAL OF SOIL STABILIZATION USING PULVERIZED COAL BOTTOM ASH

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ABSTRACT

A low calcium pulverized coal bottom ash (PCBA) is evaluated for use as a stabilizer for a residual lateritic soil. The laboratory study consisted of the following tests conducted on soil - PCBA mixtures compacted at the energy level of the standard Proctor: moisture - density relationship, unconfined compressive strength (UCS), California bearing ratio (CBR) and durability by immersion in water. Moderate increases in strength and durability were recorded on treating the lateritic soil with an optimum 6% PCBA content. Testing methods and recommendations for mix design of PCBA stabilized pavement subgrade are presented and the mechanism of PCBA cementation is discussed.

KEYWORDS

California bearing ratio (CBR), Compaction, Compressive strength, Durability, Laboratory studies, Unconfined compressive strength (UCS).

INTRODUCTION

Nigeria, like other countries of the world, is a producer of wastes which are generated from human biological processes or from industry. The most prominent wastes produced are those of agricultural, industrial, mining and municipal origin. The accumulation of these massive by-products residues present considerable environmental aesthetic, economical and social problems. However, in the industry, we deal with wastes that can be defined as materials generated as a result of normal operations over which we have control in terms of their production, disposal or discharge. Wastes in this sense do not therefore connote worthless substances as they may be economically utilized for construction purposes.

Coal ash is an engineering material and its use is similar to the use of competing virgin, processed and manufactured materials in that it is affected by local and regional factors. These factors include production rates, processing and handling costs, transportation costs, availability of competing materials, seasonal adjustments, and the experience of materials specifiers, design engineers, purchasing agents, contractors, legislators, regulators and other professionals (Tyson, 1993).

The combustion of coal produces a by-product consisting essentially of inorganic mineral constituents (about 3 - 30%) in the coal and organic matter, which is not fully burnt. During the combustion of coal in boiler plants, the ash is distributed into two parts namely, the bottom ash that is collected at the bottom of the boiler unit and the fly ash collected mostly by air pollution control (APC) equipment through which the stack gases pass.

Nigeria has over 1.5 million metric tonne of proven and inferred coal reserves (United Nations, 1979). However, the use of coal by the major users has diminished since the dieslization of the Nigerian Railway Corporation (NRC) and the gasification of thermal generating plants by the National Electric Power Authority (NEPA). Several studies have been carried out on the use of fly ash and the results of these studies have shown that they can be very useful for several engineering purposes. Most of the studies conducted were motivated by the consideration of disposal techniques for coal ash. Despite the extensive work so far conducted on the uses of fly ash, coal bottom ash is still in an area yet relatively untouched. The aim of this study was to evaluate the use of pulverized coal bottom ash (PCBA) for soil improvement and if realised this will serve as a disposal technique for thermal stations using coal as fuel. Laboratory tests were conducted to determine whether compacted soil - PCBA mixtures with sufficient strength and durability could be produced for use as stabilized subgrades.

CHEMICAL ASPECTS OF PULVERIZED COAL BOTTOM ASH (PCBA)

Cement Rating

The cementing characteristics of PCBA is a function of the chemical/mineralogical changes that occur when coal is fired. The oxide composition of PCBA, which is close to that of ordinary Portland cement, could be cementitious and therefore have stabilizing potential. However, the extent to which PCBA waste could stabilize is not certain. Judging from Table 1, it

is evident that except for calcium oxide (CaO), which is very low, PCBA match the composition of ordinary Portland cement (OPC).

The actual combinations of PCBA chemical components to form active cementitious compounds however, seem to limit the extent of stabilization potential developed. Table 2 shows the abundance of the essential cementitious components in PCBA as compared with that of a typical Portland cement which was calculated based on the oxide compositions in Table 1 by means of Bogue's equations (Bogue, 1955).

The basic chemistry of hydrated cement paste shows that the silicates, tricalcium silicate (C_3S) and dicalcium silicate (C_2S), are the most important compounds which are responsible for the strength. However, in the low calcium PCBA used in this study these silicates are absent. The presence of tricalcium aluminate (C_3A) in cement though undesirable is about half the quantity in PCBA. C_3A contributes little or nothing to strength at early ages and reacts with sulphates to form the expansive compound calcium sulphoaluminate (ettringite) that is responsible for the so called "sulphate attack". Tetracalcium aluminoferrite (C_4AF), which is present in cement in small quantities exceeds the corresponding amount in PCBA by about 25%. When compared with the other three compounds, C_4AF does not affect the behaviour of cement significantly, however, it reacts with gypsum to form calcium sulphoferrite and its presence may accelerate the hydration of silicates (Neville and Brooks, 1987).

Hydration of Pulverized Coal Bottom Ash

In the presence of water, the aluminates (C_3A and C_4AF) in PCBA form products of hydration, calcium aluminate hydrates (CAH), which in turn produce a firm mass. The reaction of PCBA with water is in the first instance a reaction of individual constituents. The C_3A reacts extremely rapidly, while C_4AF reacts very quickly. Consequently, the degree to which the different compounds in PCBA contribute to the strength is not the same.

SCOPE OF STUDY

The study was carried out using samples of low calcium PCBA obtained from the Nigerian Railway Corporation disposal site in Jos (Latitude 9°52.5'N and Longitude 8°52.5'E) as well as lateritic soil obtained from Zaria (Latitude 11°15'N and Longitude 7°45'E). The main aim of the study was to assess the stabilization potential of PCBA in the improvement of the bearing capacity of poor subgrade soil in road construction.

The soil used in this study is a natural reddish-brown residual lateritic soil classified as A-7-6 in the AASHTO Soil Classification System (AASHTO: Standard, 1986) and CL in the Unified Soil Classification System (ASTM, 1992) was obtained using the method of disturbed sampling. The mineralogy of the clay size fraction of lateritic soil from the study area was reported (Osinubi, 1998a,b) to comprise mainly kaolinite with some quartz. Also, the chemical composition of the soil was reported.

A study of the geological and soil maps of Nigeria after Akintola (1982) and Areola (1982), respectively, show that the natural soil belongs to the group of ferruginous tropical soils derived from acid igneous and metamorphic rocks. This is in agreement with D'Hoore (1953). The soil was characterized and classified by the tests carried out in accordance with BS 1377 (1990). The results obtained are summarized in Table 3. Fig. 1 shows the particle size distribution of the natural soil.

METHODS OF TESTING

Moisture - Density Relationships

Moisture density relationships were determined using soil samples air-dried for one day. Compaction was at the energy level of the standard Proctor because this can easily be achieved under field conditions.

Unconfined Compression

The 7 day unconfined compressive strength (UCS) of specimens was used to evaluate the potential increases in strength for lateritic soil treated with PCBA. The UCS values obtained for treated soil specimens were compared with those of untreated specimens. The unconfined compression test was used to determine the percentage of PCBA in the lateritic soil - PCBA mixture that would yield the maximum strength value. All tests were conducted in accordance with BS 1924 (1990).

Samples of soil treated with PCBA were prepared by mixing the desired proportions of soil, PCBA and water. Percentages of PCBA mixed with the natural soil ranged from 0% to 20%, by weight of dry soil, while water contents ranged from 5% to 30%. Samples were prepared by compacting the mixture in cubic moulds ($10 \times 10 \times 10\ cm^3$) using the standard Proctor compactive effort. After compaction, specimens were extracted from the moulds, waxed to prevent loss of moisture by evaporation and allowed to cure for 7, 14 and 28 days under controlled conditions (i.e. at a temperature of $25 \pm 2°C$ and a relative humidity of 100%) before being tested in unconfined compression.

California Bearing Ratio

The test for CBR described in BS 1924 (1990) was modified to conform with the recommendation of the Nigerian General Specifications (1970), which recommends that the specimens be cured for six days unsoaked and later immersed in water for one day before testing.

Durability Tests

The durability assessments of the lateritic soil - PCBA specimens were conducted by determining the loss of strength due to complete immersion of specimens in water. This was achieved by initially curing a set of waxed specimens for 7 days under controlled conditions. Subsequently, the cured specimens were de-waxed top and bottom and immersed in water for another 7 days in order to measure resistance to loss in strength rather than the Portland Cement Association wetting-drying test or freeze - thaw test as described by ASTM D559-89 and ASTM D560-89 (ASTM, 1992), respectively. Furthermore, the freeze-thaw test cannot be said to be appropriate under tropical conditions. The resistance to loss in strength was calculated as a ratio of the unconfined compressive strength (UCS) of specimens which had been tested for loss in strength to the UCS of another set of specimens, which were cured under controlled conditions for 14 days in accordance with BS 1924 (1990).

RESULTS AND DISCUSSION

Moisture - Density Relations and Strength of Soil-PCBA Mixtures

The effect of PCBA content on the maximum dry density (MDD) and optimum moisture content (OMC) of lateritic soil - PCBA mixtures are shown in Figs. 2 and 3 respectively. The MDD and OMC of PCBA treated soil decreased and increased, respectively, with increase in PCBA content. In the natural soil when moisture content is low, the soil is stiff and high densities are obtained. The observed decrease in MDD of soil - PCBA mixtures with increase in PCBA content is due to the effect of particle size distribution and specific gravities of soil and PCBA. When the lateritic soil with specific gravity of 2.66 was mixed with PCBA that had a specific gravity of 1.64, the tendency was for the soil-PCBA mixture to decrease in dry density. On the other hand, the increase in OMC recorded with increase in PCBA content was due to the larger quantity of water required for the hydration of PCBA.

The relationship between UCS of the treated soil and PCBA content is shown in Fig. 4. The optimum PCBA content for stabilization of the lateritic soil used in this study is 6%. This gave a 7 day UCS of 1275 kN/m^2 which is less than the 1700 kN/m^2 recommended by Road Note 31 (TRRL, 1977) for base material. A factor which could have affected the strength of the mixture is density. A lower MDD could have been responsible for the low strength gain. Furthermore, CaO which along with SiO_2 and Al_2O_3 are the main cementitious materials in inorganic particulate matters constitute about half the corresponding quantity in ordinary Portland cement (see Table 1). This probably also affected strength gain of the mixtures.

The CBR value of the PCBA treated lateritic soil was found to increase significantly from 8% for the natural soil to 95% at the optimum 6% PCBA content as shown in Fig. 5. Thereafter, the CBR value decreased with higher PCBA content. The results recorded show that if CBR values of 10%, 30% and 80% (standard Proctor compaction) are used as criteria to be met for subgrade, sub-base and base courses respectively, then the lateritic soil treated with an optimum 6% PCBA content is adequate for base course.

However, the Nigerian General Specification (1970) recommends a CBR value of 180% to be attained in the laboratory for cement stabilized material to be constructed by the mix-in-place method. The low gain in strength of the soil-PCBA mixture may be due to the absence of C_2S, which is a major cementitious compound. It is also possible that hydrated lime during hydration of PCBA decreased the concentration of aluminate ions, thus slowing down the rate of hydration of C_3A to form the strength producing compound of tetracalcium aluminate hydrate.

Durability of Soil-PCBA Mixtures

The lateritic soil treated with up to 20% PCBA content was tested by conducting immersion tests in water for measurement of resistance to loss in strength. The freeze-thaw and wet-dry tests, which are applicable to cement stabilized soils were not adopted because it is not known whether the same criteria are applicable to the treated soil in view of the absence of C_3S and C_2S in PCBA. The immersion test results obtained are presented in Table 4.

The resistance to loss in strength expressed as a percentage is the ratio of the soaked UCS (i.e. specimens wax-cured for 7 days, de-waxed top and bottom and later immersed in water for another 7 days) to the UCS of specimen wax-cured for 14 days. The lateritic soil mixed with the optimum 6% PCBA content recorded resistance to loss in strength of 40% (i.e. loss in strength of 60%). The loss in strength of 60% is three times the 20% allowable loss in strength for a 7 day curing dry and 4 day soaking period suggested by Ola (1974). Irrespective of the difference in soaking periods it can be said that the specimens tested failed the durability test. Probably, in order to achieve adequate durability it might be necessary to incorporate other additives like cement or lime in the lateritic soil before adding PCBA.

CONCLUSION AND RECOMMENDATION

PCBA has the potential to be used as a low-cost construction material based primarily upon increases in UCS and CBR of PCBA-treated lateritic soil. The mechanism responsible for PCBA cementation and soil stabilization appears to be particle bridging and void filling by particles of hydrated PCBA, which form cementitious compounds like calcium aluminate hydrates.

The use of only 6% PCBA by weight of dry soil, increased the 7 day unconfined compressive strength of the lateritic soil used in the study (A-7-6 and CL in the AASHTO and Unified soil Classification Systems respectively) from 375 kN/m^2 to 1275 kN/m^2. With respect to the California bearing ratio, the value increased from 8% for the natural soil to 95% for soil treated with an optimum 6% PCBA content. However, the durability exhibited using the immersion test was not acceptable. In order to achieve adequate durability it might be necessary to treat the soil with other additives like lime or cement before adding PCBA. Further research is recommended in this area.

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TABLE 1: OXIDE COMPOSITION OF PULVERIZED COAL BOTTOM ASH AND ORDINARY PORTLAND CEMENT

Oxide	Content (%)	
	PCBA	Ordinary Portland Cement*
CaO	2.24	63
SiO_2	26.4	20
Al_2O_3	9.35	6
Fe_2O_3	2.25	3
MgO	0.60	0.86
$Na_2O + K_2O$	0.35	1
Mn_2O_3	0.50	-
SO_3	0.97	2
TiO_2	0.35	-
Loss on ignition	4.45	2

x After Czernin, 1962.

TABLE 2: CALCULATED COMPOUND COMPOSITION OF PULVERIZED COAL BOTTOM ASH AND A TYPICAL PORTLAND CEMENT

Compound	Content, Percent	
	PCBA	Portland cement
C_3S	-	54.1
C_2S	-	16.6
C_3A	20.98	10.8
C_4AF	6.84	9.1

TABLE 3: TEST RESULTS OF NATURAL SOIL

Property	Quantity
Natural moisture content, %	7.10
Liquid limit, %	44.0
Plastic limit, %	24.0
Plasticity index, %	20.0
Linear shrinkage, %	9.5
Percentage passing BS No. 200 sieve	52.0
Group index	6
AASHTO Classification	A-7-6
USCS Classification	CL
Maximum dry density, Mg/m^3	1.75
Optimum moisture content, %	15.5
Unconfined compressive strength, kN/m^2	375
California bearing ratio, %	8
Colour	Reddish brown

TABLE 4: EFFECT OF IMMERSION IN WATER ON UCS OF LATERITIC SOIL - PULVERIZED COAL BOTTOM ASH MIXTURES

PCBA content, %	14 day UCS, kN/m^2	Soaked UCS, kN/m^2	Resistance to loss in strength, %
0	675	175	26
2	1025	275	27
4	1125	375	33
6	1175	475	40
8	900	285	32
10	825	275	33
15	625	225	36
20	525	200	38

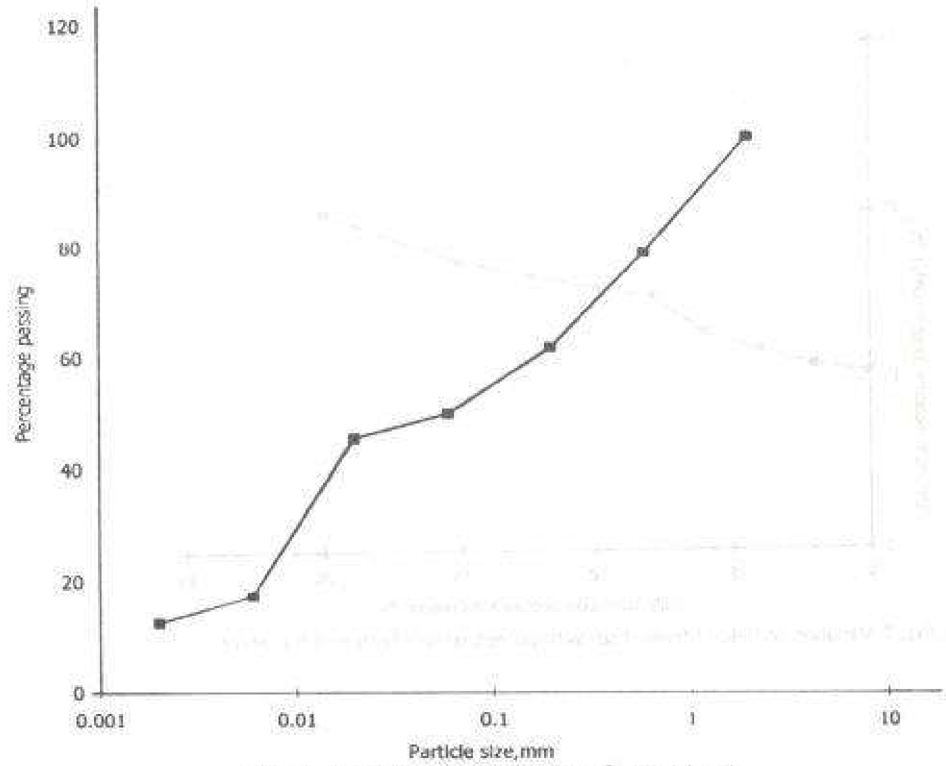

Fig. 1 Particle size distribution of natural soil

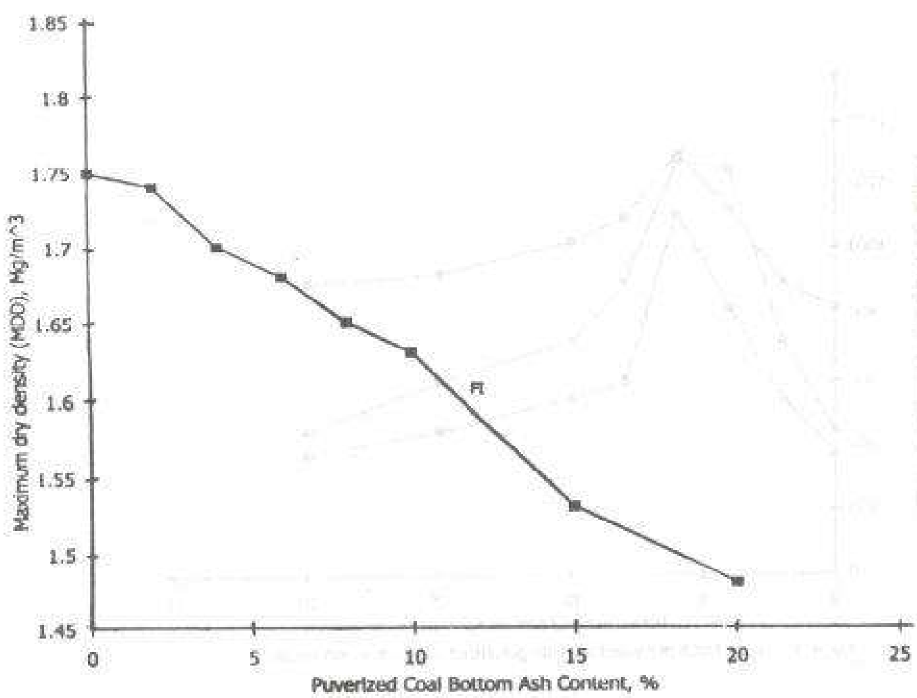

Fig. 2 Variation of MDD of treated soil with pulverized coal bottom ash content

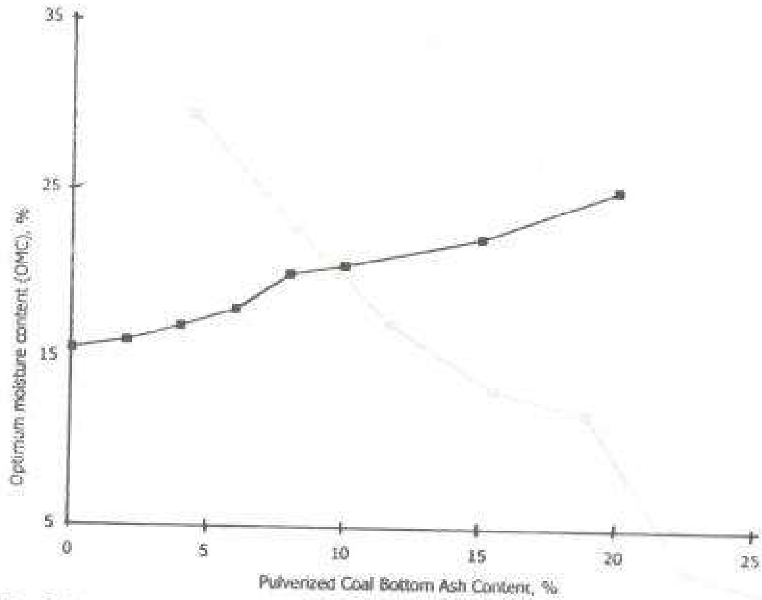

Fig. 3 Variation of OMC of treated soil with pulverized coal bottom ash content

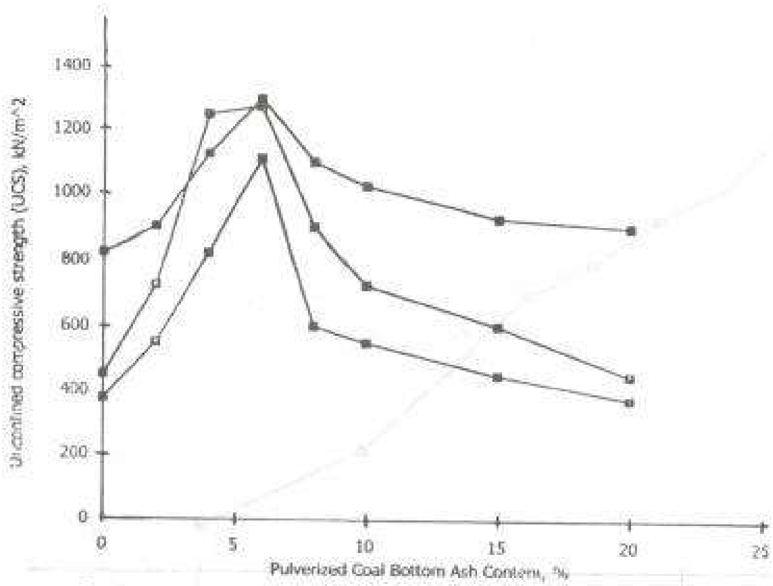

Fig. 4 Variation of UCS of treated soil with pulverized coal bottom ash content

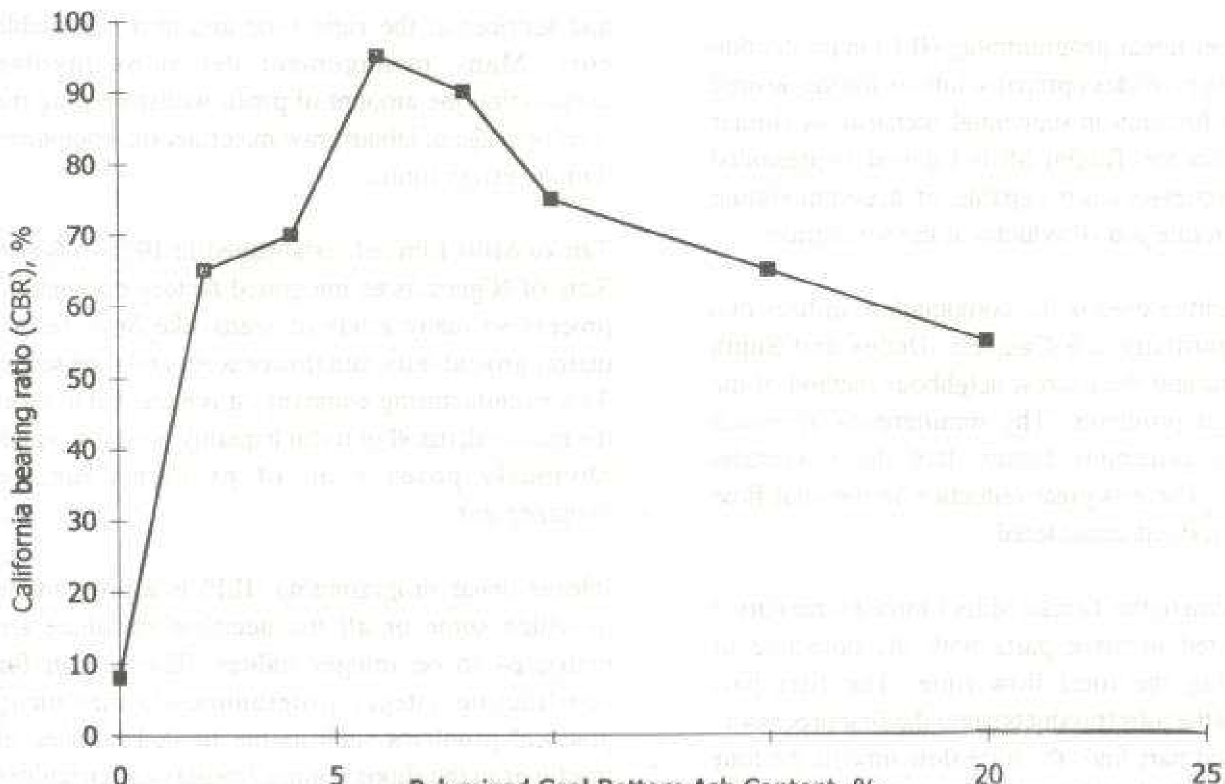

Fig. 5 Pulverized Coal Bottom Ash Content, %