Reddy *et al. Geo-Engineering* (2018) 9:23
https://doi.org/10.1186/s40703-018-0093-z

International Journal of Geo-Engineering

ORIGINAL RESEARCH

Physical, chemical and geotechnical characterization of fly ash, bottom ash and municipal solid waste from Telangana State in India

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Abstract

Utilization of fly ash, bottom ash and municipal solid waste in the field of geotechnical engineering necessitates determination of its physical, chemical, morphological and engineering properties. This paper presents detailed physical, chemical and geotechnical characterization of fly ash, bottom ash and municipal solid waste from Telangana State in India. Fly ash and bottom ash samples were collected from Kakatiya thermal power station in India. Municipal solid waste (MSW) sample was collected from Borabanda municipal dump site in the city of Hyderabad, India. From the experimental results, it is noticed that specific gravity of fly ash, bottom ash and municipal solid waste were found to be 1.86, 1.77 and 2.2 respectively. Presence of quartz and mullite; quartz, mullite and calcium carbonate; and quartz and corundum are found to be predominant in fly ash, bottom ash and MSW respectively. The peak friction angle of fly ash, bottom ash and municipal solid waste were found to be 37.02°, 33.77° and 35.23° respectively. Permeability characteristics of fly ash, bottom ash and municipal solid waste were observed to be 1.01E−04 cm/s, 2.01E−04 cm/s and 1.16E−04 cm/s respectively. From the observation of experimental results, it can be concluded that fly ash, bottom ash and municipal solid waste from Telangana state are effective material to be used as backfill material, filter material and embankment construction.

Keywords: Fly ash, Bottom ash, Municipal solid waste, Backfill material, Friction angle

Introduction

Agriculture industry, household activities, domestic and commercial activities, construction demolition along with several industries throughout the world generates waste in huge quantity (rice husk ash, municipal solid waste, coal ash, liquid waste, building debris, etc.). Due to the presence of toxic substances, these wastes are hazardous in nature and pose serious problems to the environment. To reduce these problems some of these kinds of waste have been utilized in the field of civil engineering such as geotechnical applications like land filling, soil stabilization, embankment construction etc. [1, 20, 21, 28]. Geotechnical behavior of pond ash have been studied by many researchers [18, 19].

Fly ash is a waste byproduct material generated from thermal power plants by combustion of pulverized coal. Now a days power consumption is more because of rapid urbanization which resulted in operation of more number of new thermal power plants. After combustion of coal, residue left in the electrostatic precipitator is termed as fly ash. Generally, fly ash contains micro-sized particles that consist of silicon dioxide (SiO_2), aluminum oxide (Al_2O_3) and calcium oxide (CaO). Fly ash particles are grey in colour, spherical in shape and alkaline in nature [5, 22]. Fly ash has been used as highway road embankment fill material for various highway construction projects.

Bottom ash is also a by-product of coal combustion at thermal power plants. Major chemical substance present in bottom ash contains namely, calcium dioxide (CaO), silica (SiO_2), alumina (Al_2O_3), iron oxide (Fe_2O_3) and small amount of calcium, magnesium. Chemical composition of bottom ash is similar to the fly ash but it contains greater amount of carbon [2]. Bottom ash shows higher shear strength, higher permeability and low compressibility. These properties make bottom ash as a material used in the construction of dam and for other civil engineering applications.

Industrialization plays an important role in developing countries like India, which has large population. Rapid increase of population and per capita income directly or indirectly lead to generation of high rate of municipal solid waste (MSW). Municipal solid waste and different types of industrials wastes have severe serious impact on environment. Large amount of these wastes are extremely dangerous to living human beings and animals. These types of waste bring down the quality of ground water by leachate percolation and contaminate the surrounding soil. Municipal solid waste generally contains household refuse, industries, commercial offices, hospitals, textiles, institutional, construction, street sweeping, demolition debris, dead animals and fecal matter. These wastes contain high amount of organic material, which is highly deformable and compressible under certain loading conditions [7, 17]. Based on the organic content of municipal solid waste (MSW), it is categorized into two parts, i.e. biodegradable waste and non-biodegradable waste. Biodegradable waste can be easily decomposed with the help of natural agents namely oxygen, water, ultra violet rays of sun, acid rains, micro-organisms, etc. These wastes include food waste like fruits peels, plants leaves and dead plants, egg shells, paper material, garden wastes, etc. In the decomposition process micro-organisms are converted to large portion of complex matter into small unit with the help of water and oxygen. Biodegradable waste decomposed in a few months or days. It also influences the geotechnical properties of soil like compressibility, permeability, shear strength and friction angle.

Hence, in the present study an attempt has been made to study the physical, chemical and geotechnical characterization of fly ash, bottom ash and municipal solid waste from Telangana state in India.

Literature review

Fly ash utilization with several soils (likely black cotton soils) has its effect on index properties of soils as investigated by Sivapullaiah et al. [27]. The coarseness of fly ash particle decreases the activity number and plasticity index of black cotton soils. Volume change behavior of fly ash stabilized clays studied by Phanikumar and Sharma [24] revealed effective results of swell potential and consolidation. Stabilization of expansive soils with fly ash resulted in decrease of swell potential, swelling pressure, plasticity index, activity, free swell and axial shrinkage percent with an increase in fly ash content [30]. Several field investigations revealed properties of dumped waste stabilization using cementitious materials and fly ash. Laboratory tests such as California bearing ratio (CBR) and direct shear test performed on dumped waste with addition of varying percentages of fly ash revealed that with addition of 20% fly ash, the shear strength parameters of dumped waste have increased considerably. Bottom ash has been used as light fill material in soft ground, due to its lower bulk density and excellent drainage capacity [26]. Many researchers have conducted experimental studies to determine the suitability of bottom ash to be used in backfilling material in highway embankment [4]. Several experiments have been conducted to evaluate the suitability of bottom ash as filler material in the asphalt pavement. These studies indicate that, replacement of bottom ash in asphalt mixture improve the structural stability, skid resistance and resilient modulus [3]. Past studies show that, municipal solid waste incinerator ash can be utilized in geotechnical applications such as embankments, landfills and aggregate in road construction [6].

Previous studies show that, fly ash, bottom ash and municipal solid waste (MSW) samples can be effectively used for various geotechnical fills such as, backfill material for retaining structures, filling low laying areas, highway embankment construction and to stabilize the problematic soils. Hence, in the present study physical, chemical and geotechnical characterization of fly ash, bottom ash and municipal solid waste from Telangana state in India have been investigated.

Materials used

Fly ash and bottom ash samples were collected from Kakatiya thermal power station (KTPS) which is located near Chelpur village of Bhupalapally district of Telangana State in India. Figures 1 and 2 represent KTPS fly ash and bottom ash samples respectively. Municipal solid waste (MSW) sample was collected from municipal dump site Borabanda which is located in the city of Hyderabad, Telangana State, India. Figure 3a represents dumpsite of Borabanda MSW. It contains waste such as papers, plastics, yard

Fig. 1 Kakatiya thermal power station (KTPS) fly ash

Fig. 2 Kakatiya thermal power station (KTPS) bottom ash

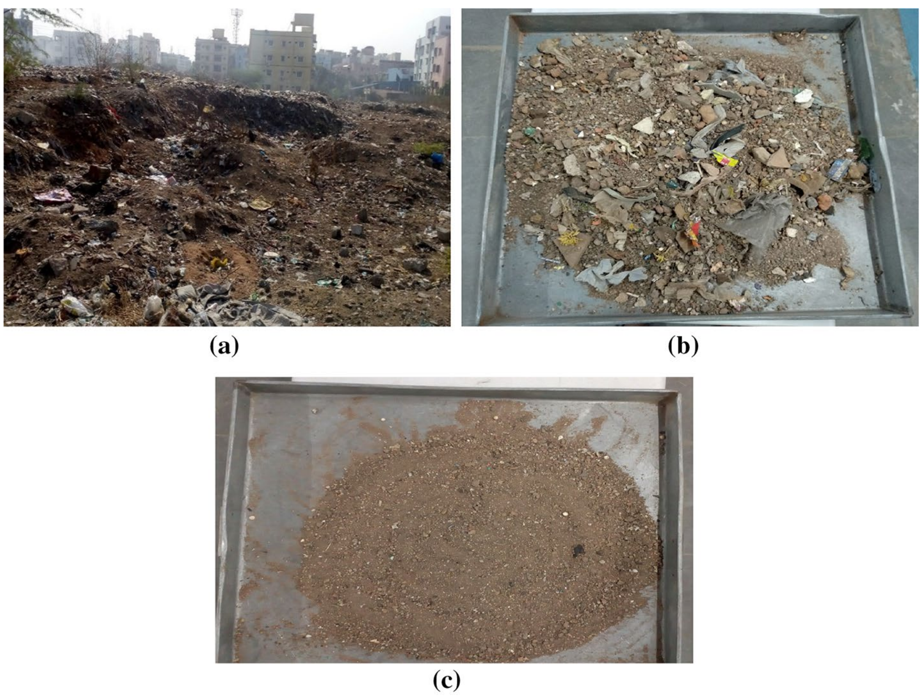

Fig. 3 **a** Typical refuse dumping site in Borabanda. **b** Collected MSW from Borabanda dump site. **c** Sample after segregation of waste material from raw MSW

debris, food waste, wood, textile wastes, bones, coconut shell, leather and other combustible materials as shown in Fig. 3b. Sample remaining after segregation of unnecessary materials from the raw MSW sample was used for its characterization as shown in Fig. 3c.

Experimental investigation

Collected fly ash, bottom ash and municipal solid waste samples have been tested in the laboratory to investigate their physical, chemical and geotechnical properties. Specific gravity test has been performed to determine the physical properties of the collected samples. X-ray diffraction (XRD) test has been performed to determine the atomic structure of crystalline substance present in fly ash, bottom ash and municipal solid waste samples. To study the morphological characteristics of fly ash, bottom ash and municipal solid waste samples, scanning electron microscope (SEM) test was performed. To know the type of mineral present in ash and municipal solid waste samples, energy dispersive X-ray (EDX) analysis was performed. Geotechnical properties like grain size, compaction, permeability and shear strength properties of fly ash, bottom ash and municipal solid waste samples have also been carried out for all three samples.

Physical characteristics

Specific gravity test

Specific gravity tests were performed for fly ash, bottom ash and MSW samples as per IS 2720 (Part-3)-1980 [9]. Considering the particle size, specific gravity of fly ash, bottom ash and MSW samples were determined using density bottles. Specific gravity is an important physical property to study the applicability of fly ash, bottom ash and MSW in the field of geotechnical engineering. Specific gravity for fly ash, bottom ash and municipal solid waste (MSW) were found to be 1.86, 1.77 and 2.2 respectively. Specific gravity of bottom ash was found to be lower than fly ash. This may be due to the presence of cenospheres and poor gradation of bottom ash. Specific gravity is influenced by following factors; chemical composition and presence of hollow fly ash particle or particles of bottom ash with porous vesicular textures. Specific gravity of MSW was found to be in agreement with past research [25]. In case of MSW, specific gravity was attributed due to the presence of decomposed organic matter.

Chemical characteristics

X-ray diffraction (XRD) test

Fly ash, bottom ash and MSW were subjected to X-ray diffraction test (XRD) to identify the minerals present in those materials. Around 10 g of each sample passing through 75 μm IS sieve was taken in a glass beaker with 5 ml of deaired water added to it. Prepared solution was then mounted on a glass slide and placed in desiccator for a day. XRD analysis was performed on this prepared sample at a scanning speed of 10°/min and step size of 0.02° with 2θ ranging from 5° to 75°. Diffractometer used in this analysis has potential difference of 40 kV and 15 mA current. The obtained XRD pattern of fly ash, bottom ash and MSW has been analyzed and matched with the standard data using X'Pert High score program to conclude their mineralogy. Figures 4, 5 and 6 represent the presence of inert material in KTPS fly ash, KTPS bottom ash and Borabanda MSW respectively. From Fig. 4, it is observed that quartz (SiO_2) and mullite ($Al_{1.69}O_{4.85}Si_{1.22}$) are predominant in KTPS fly ash. Strongest peaks of quartz are noticed at 26.52°, 20.76°, 36.44°, 42.39°, 50.04°, 59.76° and 67.87°. Similarly, the peaks of mullite are matched at 16.52°, 33.13°, 35.21°, 39.27°, 40.78°, 42.39° and 50.04°. In case of bottom ash (Fig. 5), it is observed that quartz (SiO_2), mullite ($Al_{1.69}O_{4.85}Si_{1.22}$) and calcium carbonate ($CaCO_3$) are predominant here. Strongest peaks of quartz are noticed at 26.63°, 20.77°, 49.94°, 59.85°, 67.97°, 36.44° and 45.69°. Similarly, the peaks of mullite are noticed at 16.43°, 33.13°, 35.21°, 60.78° and 60.61°. Peaks of calcium carbonate are found at 39.47° and 60.61°. From Fig. 6, quartz (SiO_2) and corundum (Al_2O_3) are found to be predominant

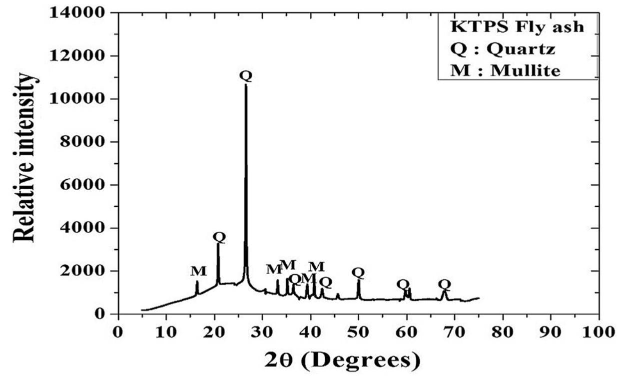

Fig. 4 X-ray diffraction pattern for KTPS fly ash sample

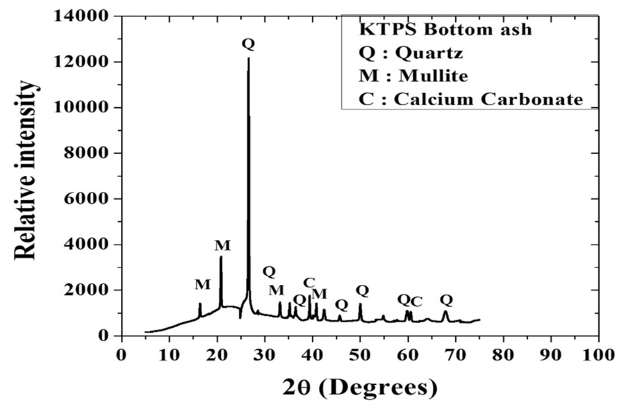

Fig. 5 X-ray diffraction pattern for KTPS Bottom ash sample

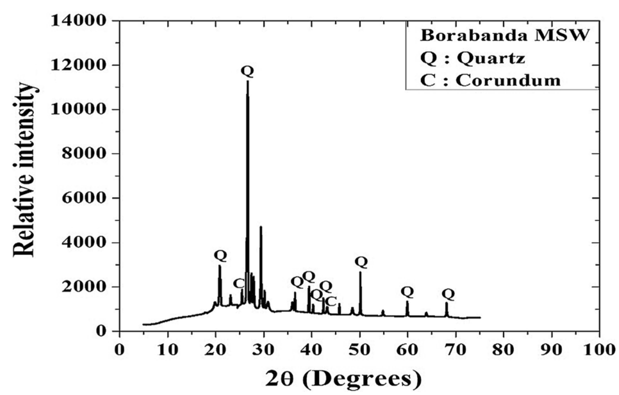

Fig. 6 X-ray diffraction pattern for Borabanda MSW

minerals present in MSW. Strongest peaks of quartz were noticed at 28.89°, 26.65°, 36.52°, 39.46°, 40.26°, 42.39°, 50.15°, 59.92° and 68.11°. Similarly, peaks of corundum were noticed at 25.49°, 43.2° and 68.11°.

Scanning electron microscope (SEM) test

Fly ash, bottom ash and MSW samples have been studied for their morphology by performing scanning electron microscope (SEM) test. Around 1 g of sample passing through 75 μm IS sieve has been taken and placed over the stub of the instrument. Then, the sample stub was placed in the vacuum chamber of SEM and when vacuum conditions reached the recommended standards, the electron beam was activated. Scanning electron microscope (SEM) scans the surface of the sample with the help of a focused beam of electrons (primary electrons) and then the images showing the morphology of the sample are obtained with the help of secondary electrons emitted from the samples. In the present study, tests were performed using SEM equipment with a 20 kV of EHT voltage and a WD of 8 mm for different magnification. SEM tests have been conducted using scanning electron microscope (SEM) facility available at Indian Institute of Technology (BHU), Varanasi, India. Scanning electron micrograph test results (SEM) of the fly ash, bottom ash and MSW samples are shown in Figs. 7, 8 and 9 respectively. It was observed that shape of fly ash particles was spherical and smooth textured surface which is similar to the observation reported by Kim et al. [16]. It was observed that bottom ash is of coarser, irregular, large size with rough surface texture in dark grey color because of the presence of unburnt carbon. Different glassy spheres, spheroids and aggregate with improper form are predominant in the bottom ash. Similar observation has also been

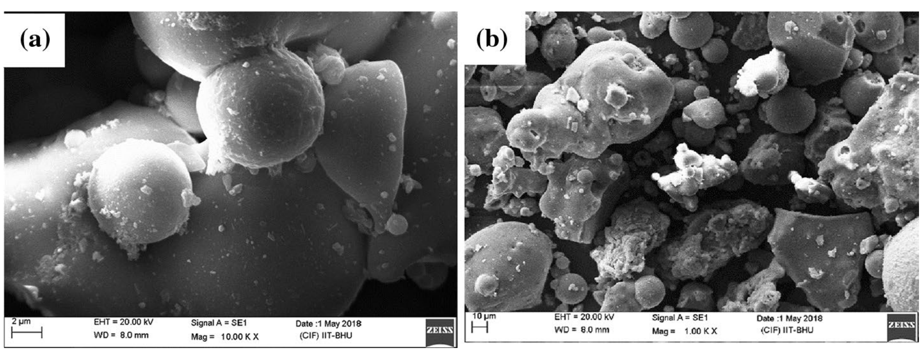

Fig. 7 SEM Micrograph for KTPS fly ash particle **a** 10.00Kx, **b** 1.00Kx

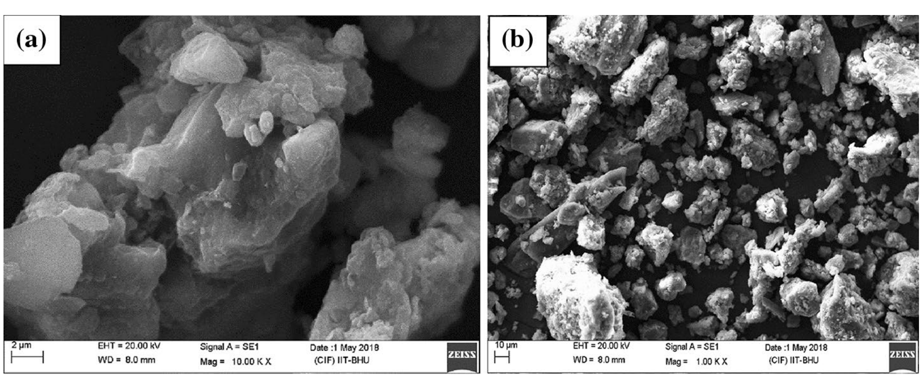

Fig. 8 SEM Micrograph for KTPS bottom ash particle **a** 10.00Kx, **b** 1.00Kx

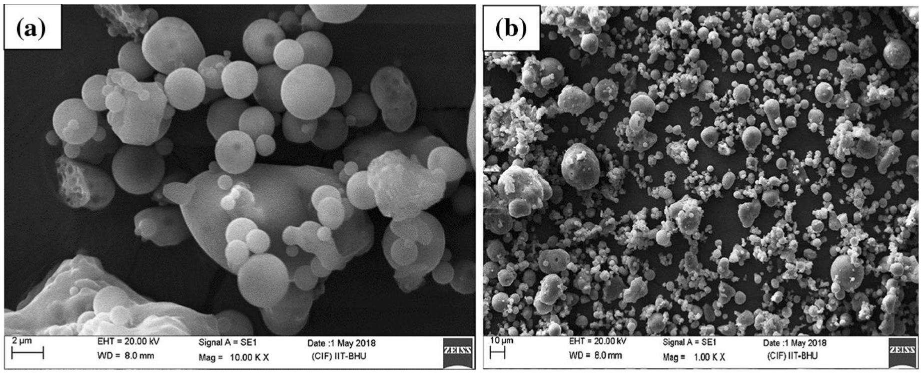

Fig. 9 SEM Micrograph for Borabanda MSW particle **a** 10.00Kx, **b** 1.00Kx

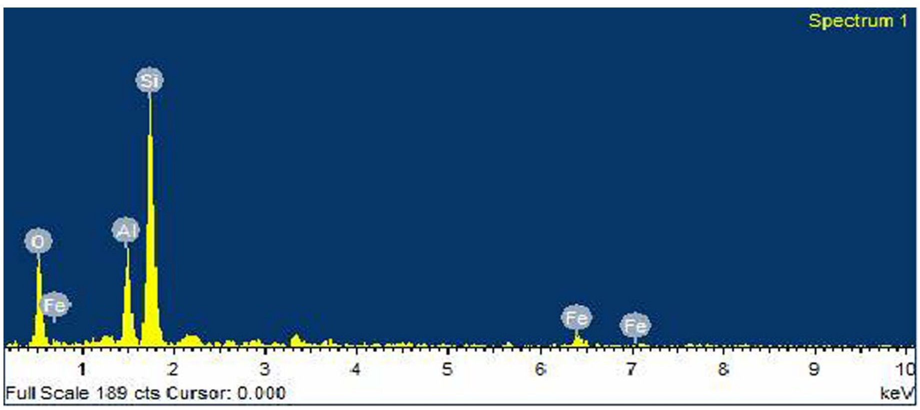

Fig. 10 Energy dispersive X-ray (EDX) graphs of KTPS fly ash

noticed by Meawad et al. [23]. MSW particles are observed to be rounded in shape and smooth surface texture.

Energy dispersive X-ray (EDX) test

Elemental composition of fly ash, bottom ash and MSW samples have been examined by energy dispersive X-ray (EDX) analysis. Each element has a characteristic energy position and based on this factor EDX test has been conducted by emitting X-rays. X-ray photons emitted by the sample are collected by the EDX instrument and converted to number of counts at each emission voltage. This total number of count obtained for a particular element is proportional to the amount of that element existing in the sample. Existing elements of a sample are identified in EDX analysis. In addition, spatially resolved chemical composition of elements can be obtained from EDX analysis. Figure 10 shows the typical EDX result of KTPS fly ash. It can be noticed that, fly ash sample contains high amount of silicon (Si), small amount of aluminum (Al), oxygen (O) and little amount of iron (Fe). However, KTPS bottom ash sample contains silicon (Si), aluminum (Al), carbon (C), calcium (Ca), potassium (K), oxygen (O), and iron (Fe) (Fig. 11). Similarly, municipal solid waste (MSW) sample contains elements of aluminum (Al),

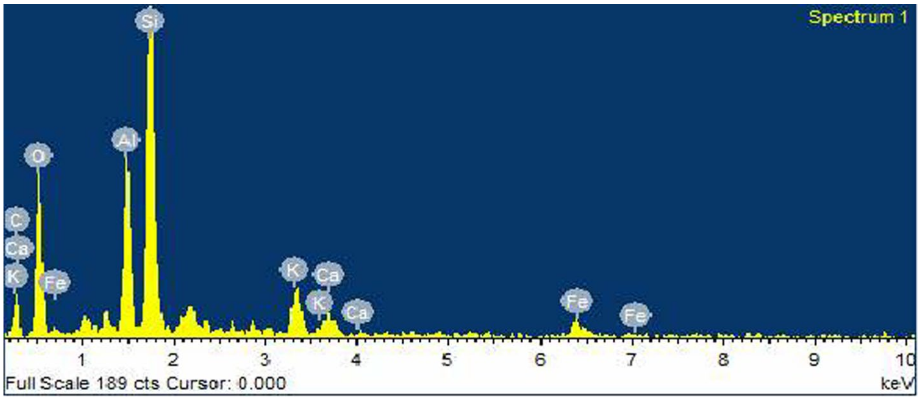

Fig. 11 Energy dispersive X-ray (EDX) graphs of KTPS bottom ash

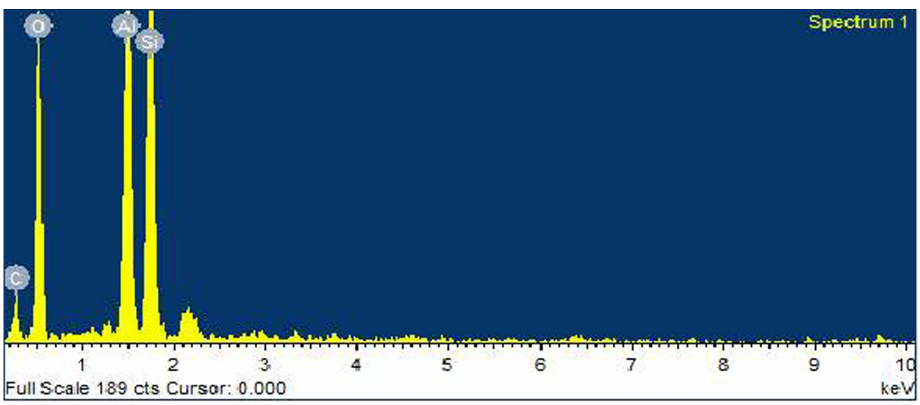

Fig. 12 Energy dispersive X-ray (EDX) graphs of Borabanda MSW

oxygen (O), silicon (Si) and carbon (C). Typical chemical composition of Borabanda MSW is shown in Fig. 12.

Geotechnical characteristics

Grain size distribution

Grain size distribution analysis was performed for fly ash, bottom ash and MSW samples as per IS 2720 (Part 4)-1985 [11]. First sieve analysis has been carried out for the three samples with sieve shaker (sieve size: 4.75, 2.36, 1.18, 0.425, 0.3, 0.15 and 0.075 mm). Hydrometer analysis was performed to categorize the fine particles present in the samples. The results of sieve and hydrometer analysis have been used to prepare gradation curve of fly ash, bottom ash and MSW samples. Figure 13 represents the grain size distribution curve of fly ash, bottom ash and MSW samples. In the present study, ash samples and MSW samples were classified as per Unified Soil Classification System (USCS). From the grain size distribution curve, the percentage of sand and silt content in KTPS fly ash and bottom ash were found to be 28.14%, 71.86% and 83%, 17% respectively. However, in Borabanda MSW the percentage of sand and silt content are found to be 77.28% and 22.72% respectively. Coefficient of curvature (C_c) and coefficient of uniformity (C_u)

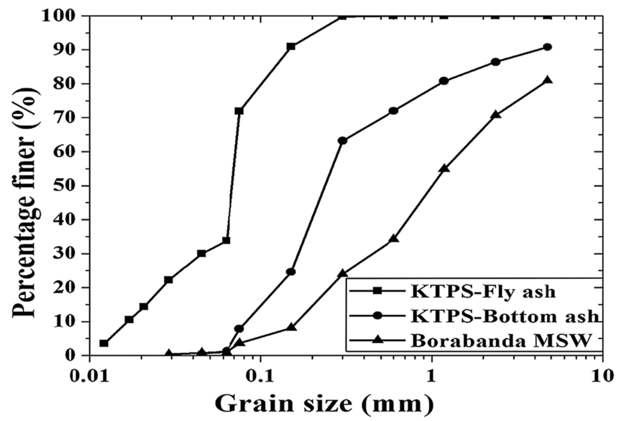

Fig. 13 Grain size distribution curve for KTPS fly ash, KTPS bottom ash and Borabanda MSW

Table 1 Grain size characteristics of KTPS fly ash, KTPS bottom ash and Borabanda MSW

Properties	KTPS fly ash	KTPS bottom ash	Borabanda MSW
Gravel % (> 4.75 mm)	0	9.2	19.06
Sand % (4.75–0.075 mm)	28.14	83	77.28
Silt % (0.002–0.075 mm)	71.86	7.2	3.95
Clay % (< 0.002)	0	0	0
Coefficient of uniformity (C_u)	3.6	4	7.866
Coefficient of curvature (C_c)	1.87	1	0.508
D_{10} size, mm	0.0170	0.067169	0.05592
D_{30} size, mm	0.04489	0.075	0.15
D_{60} size, mm	0.062862	0.15	0.6
Group symbol	Silty Sand (ML)	SP	SP

obtained for fly ash and bottom ash were 1.87, 3.6 and 1 and 4 respectively. In case of MSW, the C_u and C_c values were found to be 7.86 and 0.508 respectively. Based on Unified Soil Classification System, fly ash, bottom ash and MSW samples are categorized as sandy silt (ML), poorly graded sand (SP) and poorly graded sand (SP) respectively. Grain size distribution and gradation characteristics of fly ash, bottom ash and MSW samples are presented in Table 1.

Compaction behavior

Determination of maximum dry density (MDD) and optimum moisture content (OMC) of fly ash, bottom ash and municipal solid waste samples were carried out by performing standard proctor tests as per IS 2720 (Part 7)-1980 [10]. Oven dried fly ash, bottom ash and MSW samples have been thoroughly mixed with required quantity of water to meet the requirement of relative compaction. Mixed sample is then placed into the compaction mould and compacted in three layers with 25 blows per each layer with a 2.5 kg rammer dropped from a height of 30 cm. After completion of compaction test, specimen was extruded from mould and weighed to determine its bulk density. MDD and OMC of fly ash and bottom ash was found to be 1.29 g/cc, 19.82% and 1.01 g/cc, 40.39%

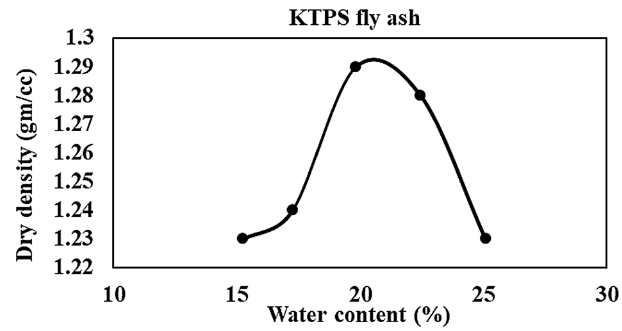

Fig. 14 Compaction curve for KTPS fly ash

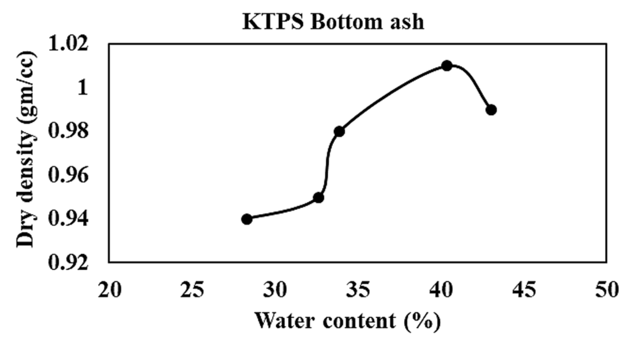

Fig. 15 Compaction curve for KTPS bottom ash

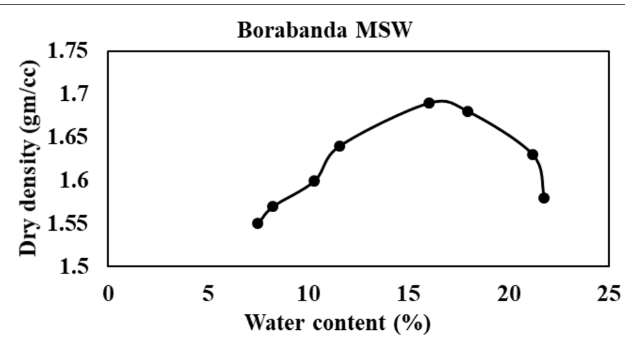

Fig. 16 Compaction curve for Borabanda MSW

respectively (Table 2). Similarly, the MDD and OMC of Borabanda MSW was found to be 1.69 g/cc and 16.05% respectively (Table 2). Fly ash shows slightly higher maximum dry density as compared to that of bottom ash. This may be due to high specific gravity of fly ash as compared to bottom ash. Figures 14, 15 and 16 represent the compaction curves of fly ash, bottom ash and municipal solid waste samples. Obtained results are in good agreement with the past studies reported by Singh et al. [29]. The maximum dry density of bottom is observed to be low, and OMC is very high. This may be due to the irregular rough surface texture and presence of unburnt carbon in bottom ash. Poor gradation and presence of cenospheres (hollow particles of large size) is the main cause for lower density of bottom ash samples.

Table 2 Compaction characteristics of KTPS fly ash, KTPS bottom ash and Borabanda MSW

Particular	OMC (%)	MDD (g/cc)
KTPS fly ash	19.82	1.29
KTPS bottom ash	40.39	1.01
Borabanda MSW	16.05	1.69

Table 3 Permeability and shear strength characteristics of KTPS fly ash, KTPS bottom ash and Borabanda MSW

Particular	Permeability (cm/s)			Angle of friction, φ (°)			Cohesion, c (kPa)		
	RC-97%	RC-98%	RC-99%	RC-97%	RC-98%	RC-99%	RC-97%	RC-98%	RC-99%
KTPS fly ash	1.01E−04	7.15E−05	3.32E−05	33.63	33.83	37.02	47.13	48.98	42.47
KTPS bottom ash	1.99E−04	1.34E−04	2.01E−04	30.62	30.07	33.77	77.73	48.17	46.07
Borabanda MSW	1.16E−04	2.87E−05	3.32E−05	33.91	32.39	35.23	40.41	38.49	47.77

Hydraulic conductivity

Hydraulic conductivity or coefficient of permeability (k) of fly ash and MSW sample was determined by falling head permeability test as the samples fall under the category of fine-grained soil. Falling head permeability test is carried out as per IS 2720 (Part-17)-1986 [12]. The bottom ash samples are found to be coarser in nature. Hence, hydraulic conductivity (k) of bottom ash sample was determined by constant head permeability test. Constant head test is performed according to IS 2720 (Part-36)-1987 [13]. Fly ash and municipal solid waste (MSW) samples were prepared at three relative compactions, i.e. 97%, 98% and 99%. While performing constant head and falling head tests, sample was saturated using de-aired water. Inlet nozzle of the mould was connected to the standpipe and flow of water was allowed until it attains steady flow. In case of falling head permeability test, time interval for a fall of head in the standpipe has been noted and was repeated five times to determine the average time interval for the same head. While in case of constant head test, time taken for a specified volume of water outflow was noted. Permeability characteristics of KTPS fly ash, KTPS bottom ash and Borabanda MSW samples are shown in Table 3. It can be observed that, the coefficient of permeability of fly ash varies from 7.15E−05 cm/s to 1.01E−04 cm/s, which is typically in the range of coefficient of permeability of non-plastic silts. Hence, in embankments and retaining walls the fly ash would perform better than normal clay, because it possesses better drainage characteristics [15]. Measured coefficient of permeability of bottom ash varies from 1.34E−04 to 2.01E−04 cm/s, which is typically in the range of coefficient of permeability of clean sand/gravel mixtures. Bottom ash particles have voids much larger than fly ash particles. Therefore, its ability to allow flow of water through it is greater than that of fly ash. Hence, bottom ash can be effectively used as road embankment construction material. The permeability of Borabanda MSW sample varies from 2.87E−05 to 1.16E−04 cm/s, which is typically in the range of coefficient of permeability of silty sand to silty clay soil.

Unconsolidated undrained (UU) triaxial shear test

Determination of shear strength parameters of fly ash, bottom ash and MSW samples have been carried out by conducting unconsolidated undrained triaxial test as per IS 2720 (Part-11)-1993 [14]. Fly ash, bottom ash and MSW samples are prepared in a mould of size 38 mm diameter and 76 mm height at three different relative compactions (97%, 98% and 99%) with the help of moist tamping technique. Selection of quantity of water for a particular density has been chosen based on the compaction curves of samples considered in this study. Each sample was prepared by three layers of compaction with a tampering rod and giving fixed number of blows to each layer. The specimen is removed from the mould and placed on the base of triaxial frame. Filter paper and porous stone was placed on top and bottom of the sample. It is then enclosed with rubber membrane and the whole assembly was sealed with o-rings. The triaxial cell is then filled with water by connecting to a pressure supply system to apply different confining pressure. The dial gauge and proving ring are set to zero before shearing. Finally shearing was done under the confining pressure of 100 kPa, 200 kPa and 300 kPa respectively. The deformation rate of 0.6 mm/min was maintained for all the tests.

Figures 17, 18 and 19 show the variation of deviatoric stress with axial strain of KTPS fly ash at different relative compaction (RC: 97%, 98% and 99%). From the result, it can be observed that behavior of deviatoric stress with axial strain is contractive in nature during static shear loading condition under different confining pressure. Peak value of deviatoric stress for samples tested at relative compaction of 97%, 98% and 99% are found to be 393.46 kPa, 760.70 kPa and 863.28 kPa; 570.41 kPa, 708.24 kPa and 1171.20 kPa; and 468.98 kPa, 784.32 kPa and 1064.99 kPa under confining pressure of 100 kPa, 200 kPa and 300 kPa respectively. Figures 20, 21 and 22 represent modified envelope failure (p–q diagram) for KTPS fly ash at different relative compaction (RC: 97%, 98% and 99%). From the results, it is observed that shear strength properties like friction angle and cohesion value for fly ash mixes at RC-97%, RC-98% and RC-99% are

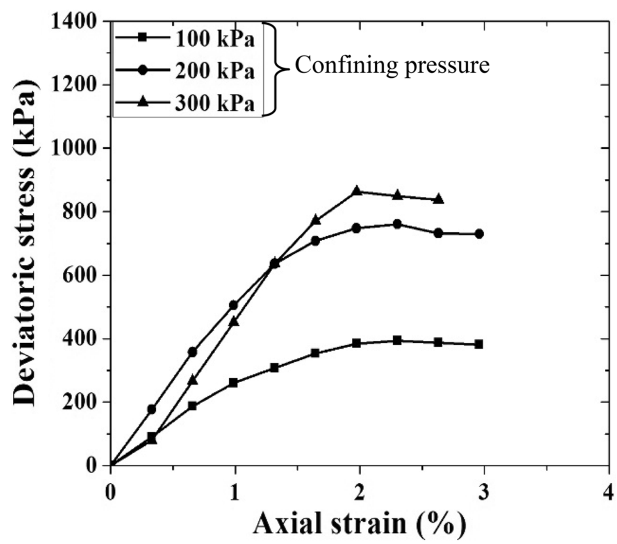

Fig. 17 Stress strain behavior of KTPS fly ash at RC-97%

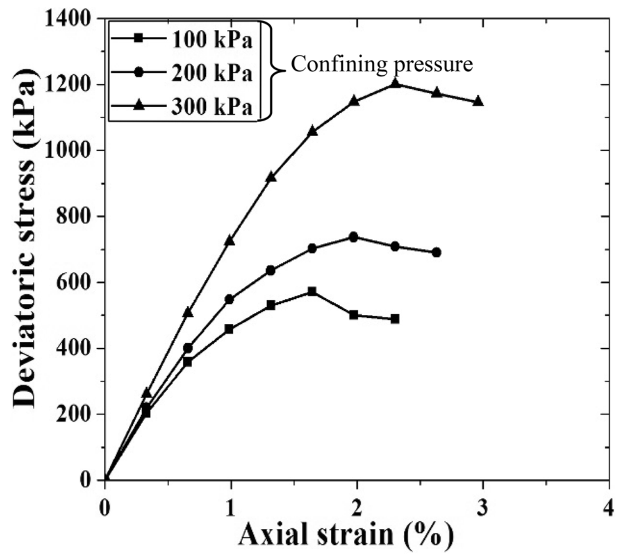

Fig. 18 Stress strain behavior of KTPS fly ash at RC-98%

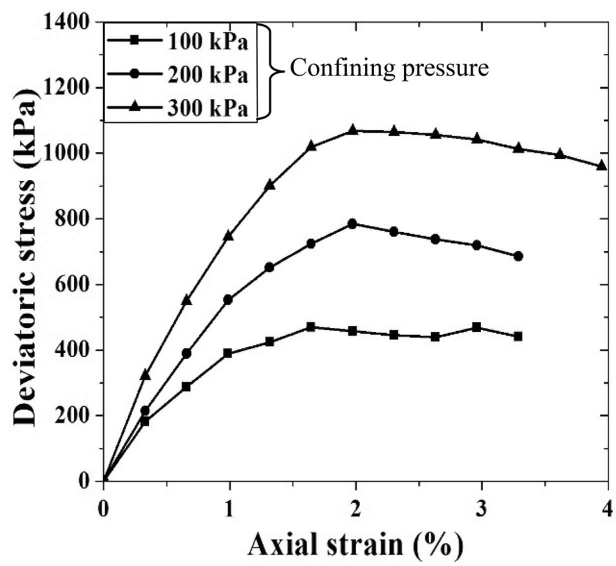

Fig. 19 Stress strain behavior of KTPS fly ash at RC-99%

33.63°, 33.83°, 37.02° and 47.133 kPa, 48.98 kPa, 42.47 kPa respectively (Table 3). The friction angle of fly ash depends primarily on the angularity of fly ash particles, which provides higher resistance to particle rearrangement for sustained. Measurable cohesion is achieved in fly ash under moist condition. Thus, it can be used as a backfill and construction material.

Figures 23, 24 and 25 represent variation of deviatoric stress with axial strain of KTPS bottom ash at different relative compaction (RC: 97%, 98% and 99%). Similar contractive behavior have also been noticed for bottom ash samples. Deviatoric stress value of bottom ash for RC 97% under the confining pressure of 100 kPa, 200 kPa and 300 kPa

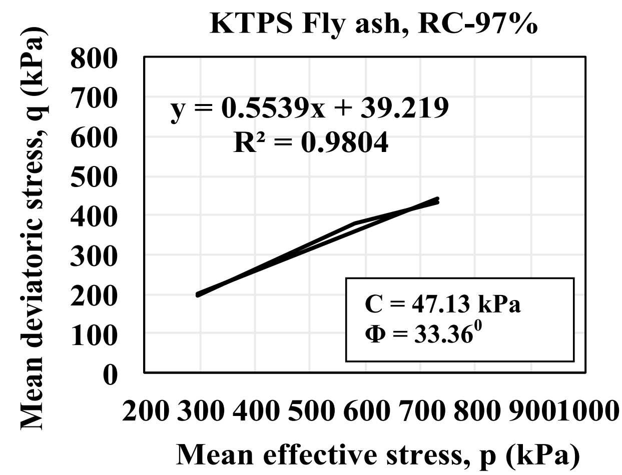

Fig. 20 p–q diagram of KTPS fly ash at RC-97%

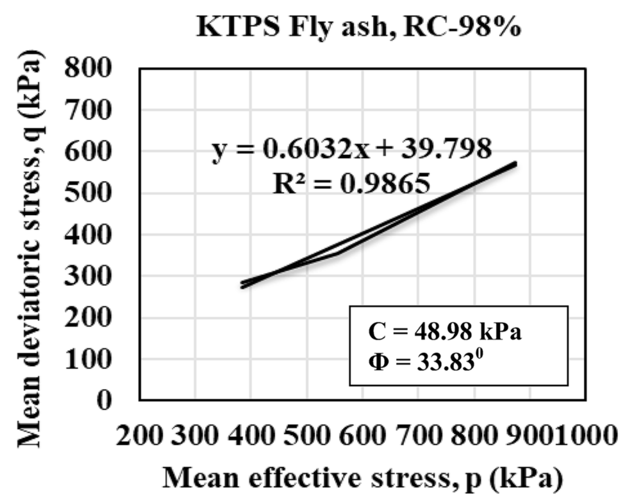

Fig. 21 p–q diagram of KTPS fly ash at RC-98%

was found to be 464.14 kPa, 724.95 kPa and 879.03 kPa respectively. In the case of 98% relative compaction under the same confining pressure deviatoric stress was observed to be 350.31 kPa, 630.82 kPa and 740.22 kPa while for 99% relative compaction, the values are found to be 448.05 kPa, 648.415 kPa and 981.84 kPa respectively. Figures 26, 27 and 28 represent modified envelope failure (p–q diagram) for KTPS bottom ash at RC-97%, RC-98% and RC-99%. From the results, it is observed that the shear strength properties like friction angle and cohesion value for bottom ash at RC-97%, RC-98% and RC-99% are 30.62°, 30.07° and 33.77°; and 77.73 kPa, 48.17 kPa and 46.07 kPa respectively (Table 3). The friction angle of each sample was in the range of 30°–40°, and it can be used as a light weight embankment material.

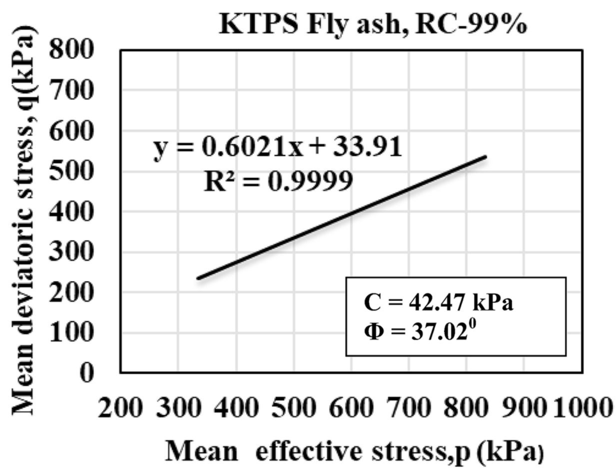

Fig. 22 p–q diagram of KTPS fly ash at RC-99%

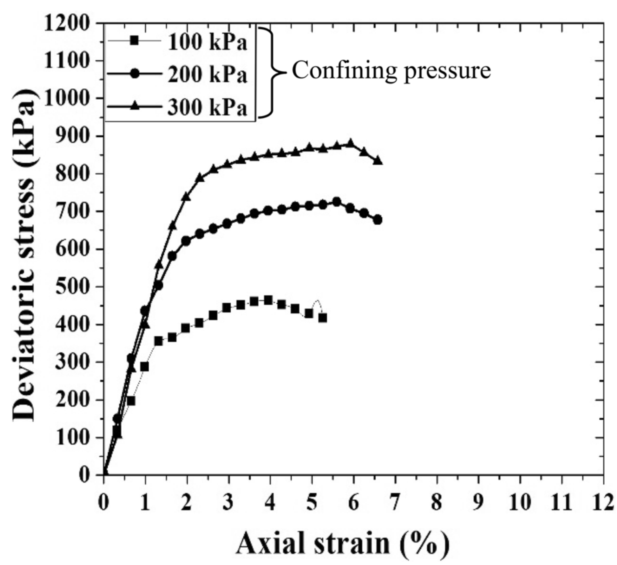

Fig. 23 Stress strain behavior of KTPS bottom ash at RC-97%

Figures 29, 30 and 31 represent the variation of deviatoric stress with axial strain for Borabanda MSW samples at different relative compaction (RC: 97%, 98% and 99%). The peak deviatoric stress value of sample at RC-97% under the confining pressure of 100 kPa, 200 kPa and 300 kPa was found to be 352.99 kPa, 463.15 kPa and 594.18 kPa respectively. In the case of RC-98% under the same confining pressure peak deviatoric stress value was observed to be 347.36 kPa, 805.56 kPa and 979.71 kPa while that at RC-99% peak deviatoric stress values are found to be 461.33 kPa, 784.92 kPa and 1045.43 kPa under the confining pressure of 100 kPa, 200 kPa and 300 kPa respectively. Figures 32, 33 and 34 represent the

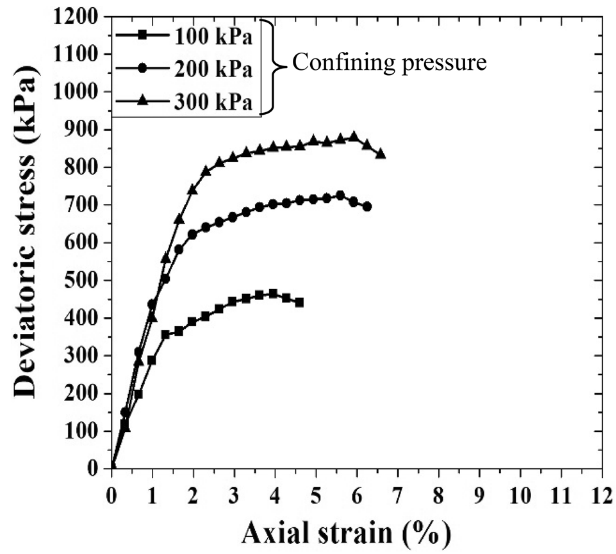

Fig. 24 Stress strain behavior of KTPS bottom ash at RC-98%

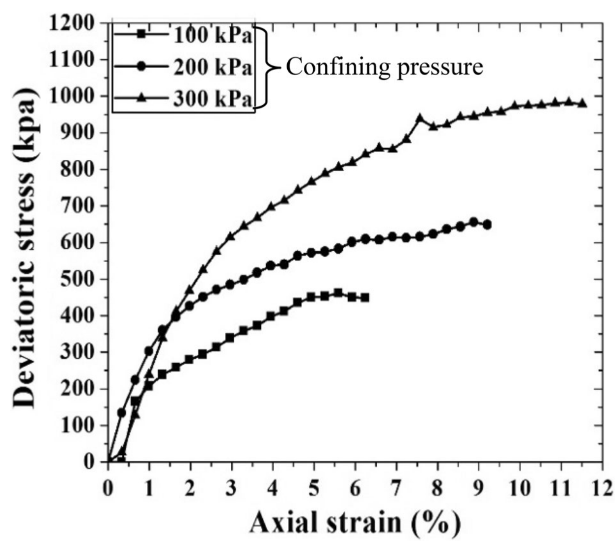

Fig. 25 Stress strain behavior of KTPS bottom ash at RC-99%

modified envelope failure (p–q diagram) for Borabanda MSW at RC-97%, RC-98% and RC-99%. From the results, the friction angle and cohesion values for MSW mixes at RC-97%, RC-98% and RC-99% were observed to be 33.91°, 32.39°, 35.23° and 40.41 kPa, 38.49 kPa and 47.77 kPa respectively (Table 3). Gomes et al. [8] reported that the value of friction and cohesion of MSW in the range of 14.2°–50.2° and 0–59.5 kPa respectively. From the above observation, the angle of friction of MSW is found to be slightly more than that of bottom ash. Hence, it can also be used as a light weight fill material.

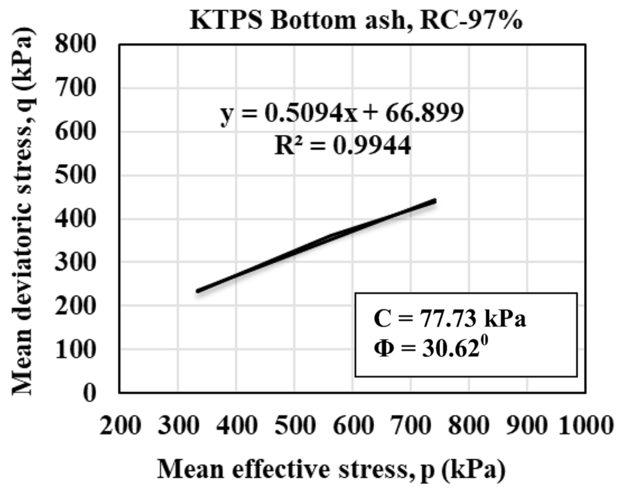

Fig. 26 p–q diagram of KTPS bottom ash at RC-97%

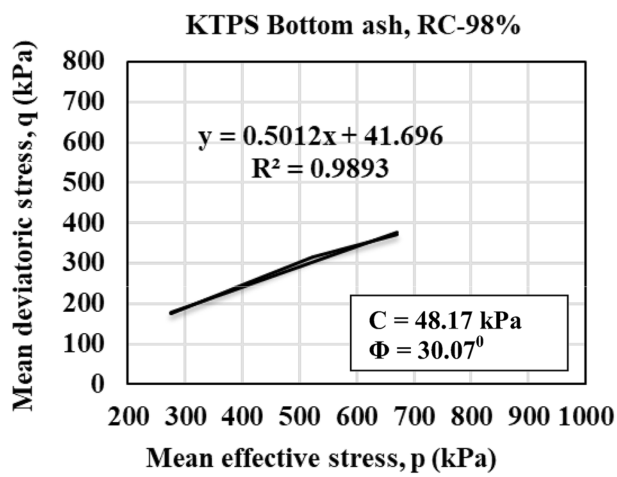

Fig. 27 p–q diagram of KTPS bottom ash at RC-98%

Conclusions

Different physical, chemical and geotechnical tests were conducted on fly ash and bottom ash collected from KTPS and MSW collected from Hyderabad city to study the physical, chemical, morphological and engineering characteristics. Based on the laboratory study following conclusions are made:

1. Specific gravity of fly ash and bottom ash found to be less as compared to MSW.
2. Presence of quartz and mullite; quartz, mullite and calcium carbonate; and quartz and corundum are found to be predominant in fly ash, bottom ash and MSW respectively.

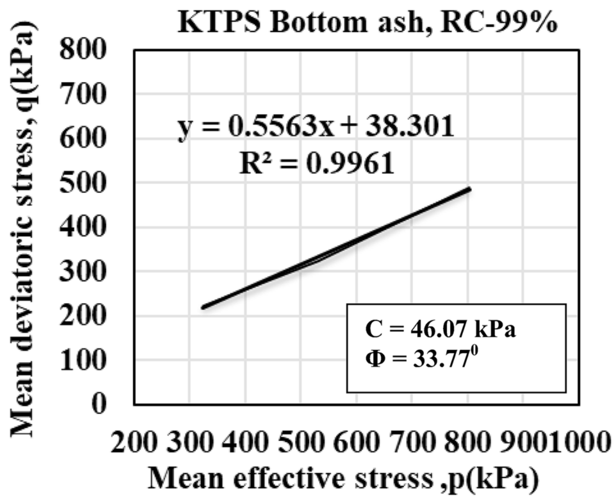

Fig. 28 p–q diagram of KTPS bottom ash at RC-99%

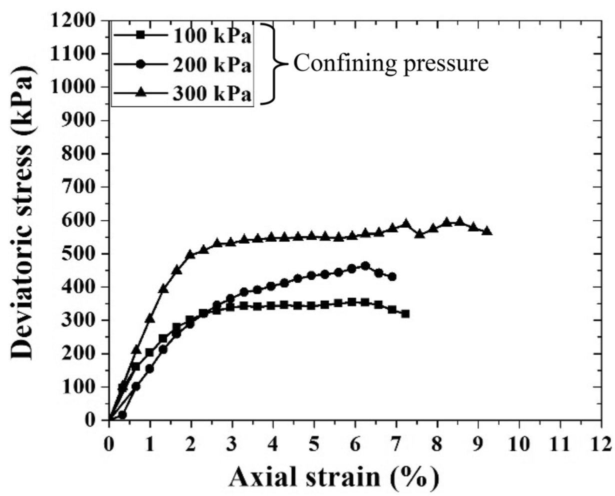

Fig. 29 Stress strain behavior of Borabanda MSW at RC-97%

3. Presence of various element like silicon, aluminum, oxygen and iron; silicon, aluminum, carbon, calcium, potassium, oxygen, and iron; and aluminum, oxygen, silicon and carbon are noticed in fly ash, bottom ash and MSW respectively.
4. The grain size distribution curves of KTPS fly ash shows that major portion of fly ash are finer particle, i.e. silt fraction with some sand fraction which can be used as a fill material in road construction.
5. The grain size distribution curves of KTPS bottom ash and Borabanda MSW shows that major portion of samples contain courser particle, i.e. sand fraction which can be used as a back fill material in retaining structures, embankment fills and fill material in low laying areas.

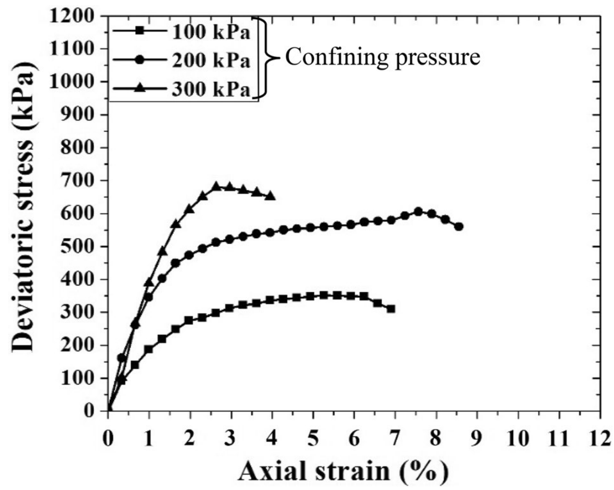

Fig. 30 Stress strain behavior of Borabanda MSW at RC-98%

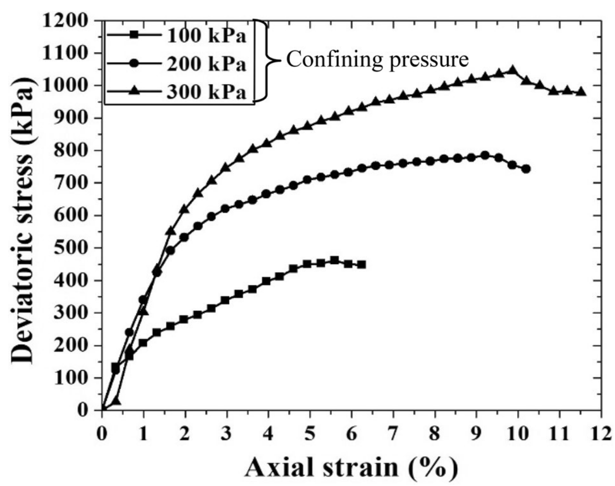

Fig. 31 Stress strain behavior of Borabanda MSW at RC-99%

6. Because of low specific gravity of KTPS fly ash and bottom ash, they exhibits lower value of maximum dry density (1.29gm/cc and 1.01gm/cc). This reduced weight can be advantage in the application as backfill for retaining walls.
7. The coefficient of permeability of KTPS fly ash varies from 7.15E−05 to 1.01E−04 m/s, which lies in silt range and can be used as material for soil stabilization.
8. The coefficient of permeability of KTPS bottom ash and Borabanda MSW varies from 1.34E−04 to 2.01E−04 cm/s and 1.16E−04 to 2.87E−05 cm/s respectively, which lies in the range of sandy soil and can be used as fill material.
9. The angle of friction of KTPS fly ash and bottom ash varies from 37.02° to 33.83° and 30.03° to 33.77° respectively. However, in Borabanda MSW the angle of friction is varies from 35.23° to 33.91°.

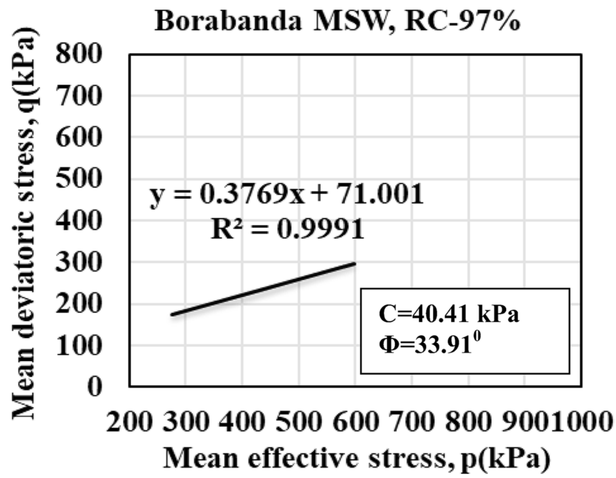

Fig. 32 p–q diagram of Borabanda MSW at RC-97%

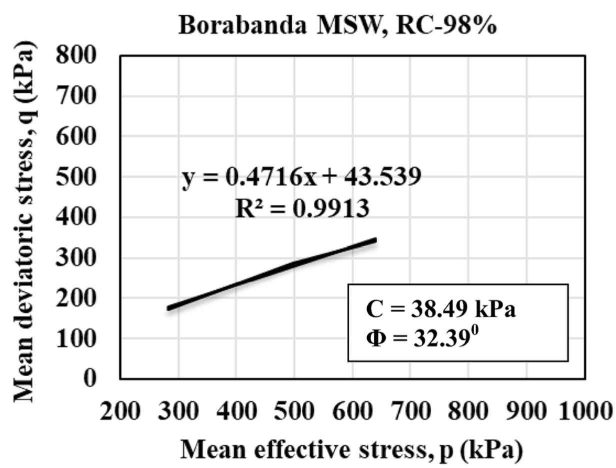

Fig. 33 p–q diagram of Borabanda MSW at RC-98%

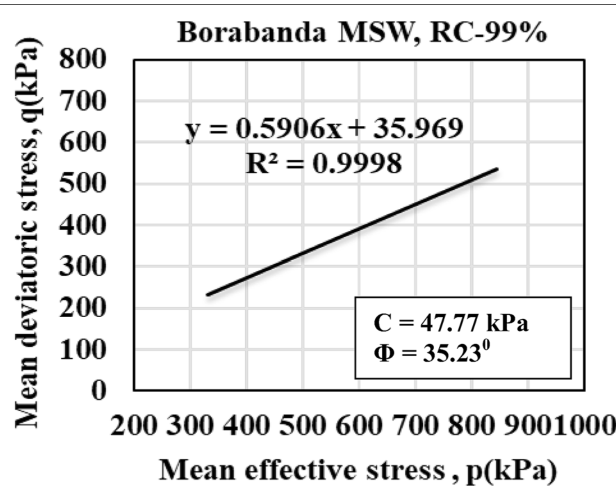

Fig. 34 p–q diagram of Borabanda MSW at RC-99%

From the above results, it is observed that fly ash, bottom ash and MSW has good potential for used as a martial for geotechnical applications like back fill martial, embankment construction and fill material, etc. The main advantage of fly ash is its low unit weight and high shear strength. The pozzolanic activity of fly ash imparts additional strength and very little settlements, making it more suitable for embankment material. Bottom ash can also be used as a construction material for highway and pavements. The MSW possess adequate shear strength which can enhance the stability of highway embankments.

Abbreviations
KTPS: Kakatiya thermal power station; MSW: Municipal solid waste; XRD: X-ray diffraction; SEM: scanning electron microscope; EDX: energy dispersive X-ray; IS: indian standard; OMC: optimum moisture content; MDD: maximum dry density; USCS: unified soil classification system; UU: unconsolidated undrained.

Authors' contributions
CSR had conducted the detailed physical, chemical and geotechnical characterization of fly ash, bottom ash and municipal solid waste from Telangana State in India as a part of MS dissertation. SM and RS had given the research idea, helped in performing experiments and participated in drafting the manuscript. All authors read and approved the final manuscript.

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Competing interests
The authors declare that they have no competing interests.

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Received: 22 June 2018 Accepted: 27 November 2018
Published online: 15 December 2018

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