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Use of Burnt Municipal Solid Waste and Lime in Local Subgrade Soil Stabilization for its Use in Low Traffic Volume Roads

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***Abstract* — *Increased human activity and urban agglomeration have, of late added critical dimensions to environmental planning and solid waste management. The present day conventional practices of on-site-land disposal method of municipal solid wastes (MSW) are creating environmental pollution and health hazards. MSW generated from the house holds of Warangal city in the burnt form is taken for demonstration and investigative study for its use in stabilization of local subgrade soils. A comprehensive data collection through primary house-hold survey using a structured questionnaire is conducted on residential waste, collection, transportation, disposal for its quantification and characterization. Waste samples were collected from the disposal site and is analyzed for their engineering properties in un-burnt and burnt forms. Sub grade soil samples from a rural area near Chintagattu village in Warangal District of Telangana State in India were collected and are examined for its compaction characteristics, CBR value and strength characteristics. Laboratory experimental investigations are carried for the use of Burnt Municipal Solid Waste (BMSW) in local subgrade soil stabilization in presence of lime. Optimum percentage of lime is arrived at based on un confined compressive strength(UCS) and CBR value criteria. Experimental, investigations are carried on local subgrade soil, soil-lime mix and soli-lime- BMSW mix for assessing the engineering properties and their use in construction of secondary roads. Experimental investigation results are encouraging and revealed that local soils can be stabilized by using BMSW ash (20%) in presence of lime(4%) for the significant improvement in strength and reduction in pavement overlay thickness up to 30%.*

Keywords* — *Municipal Solid Waste (MSW); Burnt Municipal Solid Wate (BMSW) Subgrade Soil Stabilization. BMSW and lime soil mix stabilization.

I. INTRODUCTION

Solid Waste (SW) is the material that arises from various human and economic activities. It is being produced since the beginning of civilization. In the past they were conveniently disposed off on to open lands due to low population density and abundant availability. Ever increasing population growth, urbanization and industrialization is causing in generation of large quantities of solid waste. Increased waste generation and non-availability of lands for safe disposal is of serious concern to the Municipal Administration. Despite spending 40-50 percent of Municipal service budget on solid waste disposal, most of the Indian Municipalities are unable to provide satisfactory solid waste management services. Often the solid waste disposal sites are away from urban limits and there is a need to find eco-friendly disposal solutions for MSW disposal and re use.

There is a basic difference in composition of Municipal Solid Waste (MSW) generated in developing countries and developed countries. India, being a developing country cannot adopt waste disposal methods followed in developed countries. The conventional methods available for solid waste disposal are land filling, incineration, and composting and bio-gas generation. Composting and Bio-gas generation methods are attempted but could not go commercially on large scale due to practical difficulties in implementation. Also the other issues involved in biogas and composting are operational, maintenance and marketing related. The incineration method of disposal is not adoptable due to huge capital investment. As such most of the tier-I and tier II city municipalities in India are disposing the waste on to open land. On land disposal

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method leads to pollution of ground water due to percolation of leachate and more over it become impracticable in near future to continue with open land dumping, due to scarcity of dumping sites.

This necessitates adoption of suitable cost effective methods for safe disposal of MSW. The quantity and composition of waste generated from residential communities in Indian cities depends on various factors such as land use characteristics, socio- economy, living habits, climatic conditions etc. Hence solid waste management is to be treated as an integrated activity involving its generation, transfer, storage collection, transport, processing disposal etc. which are environmentally compatible and requires involvement of multidisciplinary faculties. Taking the above said factors into consideration a holistic study is taken up for the integrated solid waste management and its reuse. MSW of Warangal city is taken as a case study for investigations and demonstration.

II. LITERATURE REVIEW

Technological developments, people's purchasing power coupled with changing life styles resulted in increase in waste generation in Indian cities. The per capita waste generation rate in India has increased from 0.44 kg/day in 2001 to 0.5 kg/day in 2011. Per capita waste generation in Indian cities varies across the regions due to socio economic and cultural factors and it ranges between 200 - 870 grams/person/day and also it is established that per capita waste generation is increasing by about 1.3% per year in India [1].

The Census of India classified Indian cities and towns into four classes, as Class 1, Class 2, Class 3, and Class 4, depending upon their population. All together there are about 53 cities with a population range of 0.7 Million to 5 Million. These urban areas altogether generate 86,000 tons per day (TPD) (31.5 million tons per year) of MSW at a per capita waste generation rate of 500 grams/day. The total MSW generated in urban India is estimated to be 68.8 million tons per year (TPY) or 188,500 tons per day (TPD) of MSW. These cities are in the process of rapid urbanization and significant in generation of MSW. Waste generation among these cities fell in a narrow range of 0.43-0.55 kg/person/day. Per capita waste generation (MSW) in cities of less than 5M population is significantly less compared to the six metropolitan cities (0.6 kg/day). Despite the lack of data among Class 2, 3, and 4 towns, the 366 cities and towns represent 70% of India's urban population and provide a fair estimation of the average per capita waste generation in Urban India (0.5 kg/day) [2]. Per capita MSW generation among different cities in India are presented in Table-1

Table.1: Per Capita Waste Generation Rate depending upon the Population Size of Cities and Towns

City Classification	City Classification Population Range (2001 Census)	No. of Cities	Per Capita kg/day
Metropolitan	5,000,000 Above	6	0.605
Class A	1,000,000 - 4,999,999	32	0.448
Class B	700,000 - 999,999	20	0.464
Class C	500,000 - 699,999	19	0.487
Class D	400,000 - 499,999	19	0.448
Class E	300,000 - 399,999	31	0.436
Class F	200,000 - 299,999	58	0.427
Class G	150,000 - 199,999	59	0.459
Class H	100,000 - 149,999	111	0.445
Class 2	50,000 - 99,999	6	0.518
Class 3	20,000 - 49,999	4	0.434
Class 4	10,000 - 19,999	1	0.342
TOTAL		**366**	

Source: CPCB (2000)

Also the latest statistics of (December 2015) Bruhat Bengaluru Mahanagara Palike (BBMP), reveals about 3000 tons per day of municipal solid waste is being generated out of which household contribute to 54% of total waste, commercial establishments generate about 25% of waste. Major physical composition of waste includes Vegetable Waste, Paper, Plastic, Textiles, Grass, Metals and Biomedical Wastes. The calorific value of the waste composition ranges from 684 to 1240 kJ/kg.[3]. Steady increase of MSW in in small and medium cities and urban local bodies(ULB), lack of infrastructure to handle MSW and scarcity of land fill sites put up tremendous pressure on budget resources to handle MSW operations. As per business as usual (BAU) scenario estimates, by 2021 MSW generation among urban local bodies would need at least 590 Sq.km of area for land filling operations which is greater than the largest urban agglomeration of greater Hyderabad area [4,5]. Ranjith Kharvel Annepu (2012) carried extensive study on present status of Solid waste management on a sample of Indian cities and examined the prospects of introducing improved means of disposing municipal solid waste (MSW) in India [6]. Such difficulties are paving the way for building regional landfills, waste to Energy (WTE) and mechanical biological treatment (MBT) solutions. The tremendous pressure on the budgetary resources of States/ULBs due to increasing quantities of MSW and lack of infrastructure has helped them involve private sector in urban development [7]. GOI has also invested significantly in solid waste management (SWM) projects

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under the 12th Finance Commission and Jawaharlal Nehru National Urban Renewal Mission (JnNURM). The financial assistance provided by GOI to states and ULBs amounted to USD 510 million (INR 2,500 crores) [7].

III. AIM AND OBJECTIVES OF THE STUDY

The aim of the study is to examine the possibilities of use of burnt municipal solid waste in local subgrade soil stabilization. The specific objectives of the study would include

- To examine the characteristics of MSW
- To examine the physical and mechanical properties of BMSW.
- To examine the engineering properties of local subgrade soils.
- To examine the improved engineering properties of stabilized subgrade soil with lime and BMSW mix at different proportions.

IV. METHODOLOGY AND DATA COLLECTION

Study Area: Warangal is the second largest town in Telangana region of newly established Telangana state with cultural and historical background. It is situated between latitude of 18°-0'-4" North and 79°-4'-25" East longitude and is located on Madras- Delhi section of South Central Railway. The normal temperature of the area varies as low as 20°C in winter to as high as 47°C in summer.

Population and Land Use Pattern:

Warangal Municipal Corporation (WMC) consists of three Major urban settlements namely Warangal (Old Town), Hanamkonda (Newly Developed Town) and Kazipet (A Railway Junction, and Railway Colony) and 42 villages extended to rural areas in the Metro region with a population of about 8.11 lacs (2011 census) and spread over an urban agglomeration of 471.746 sqkm (157.44 sqmi) under the administration of Greater Warangal Municipal Corporation (GWMC) [8] (Figure-1). Whereas the Municipal civic operations are extended to 110 sqkm as per the discussions with the GWMC officials, recorded decadal growth rate of GWMC between 2001 and 2011 was 2.64%. Based on the previous demographic trends expected decadal growth rate for the period 2011-21 would be 2.0% and the projected population GWMC for the year 2016 would be 8.95 lacs. There are also about 84 slums with a population of about 1.60 lacs. Warangal urban area is divided in to 25 residential zones. Major business and work locations in Warangal Municipal corporation limits as found from the research studies are Hanma konda, Kazipet, Warangal Market area and new upcoming development areas along Karim Nagar Road [9].

Fig.1: Tri City Kazipet-Hanmakonda-Warangal Municipal Corporation

Present Waste Disposal:

The Warangal Municipal Corporation (WMC) is responsible for collection, transportation and disposal of waste. At present waste generated from individual houses, apartments are collected and are deposited in to the dustbins placed at the street corners. The waste from the bins is collected by the trucks at regular intervals. Also the street sweepings and open drain cleanings are collected and deposited in to the dust bins. As such the MSW is containing significant amount of street sweepings which are largely silt and soil. For quantification MSW data was collected from the residential wards of WMC with a structured questionnaire using trained under graduate engineering students. The quantity of waste generated was estimated to be more than 250 tons/day. The collected waste is being disposed on to lands in low laying areas and open lands in different parts of the Warangal, Hanmakonda and Kazipet settlements. At present collected waste is disposed on to land sites at Ursugutta Paidipalli, Mamnoor, Unikicharla, Gorrekunta, Chintagattu, Kothapalli, Taralapalli, Ammavaripet, and Dharmasagar area which are distributed geographically over Greater Waranagal Muncipal corporation area. MSW disposal sites are shown in the figures 2A, 2B and 2C below.

Fig.2A: MSW collection and dumping at house hold level from Mixed Land uses in WMC

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Fig.2B: MSW on site land disposal in WMC

Fig.2C: MSW disposal on to open land site in WMC

Qualification of Waste:

Decadal population details collected from the census are examined for various projection methods like arithmetical, geometrical, incremental increase etc., It is observed that Warangal Hanmakonda –Kazipet being a Tri City experienced rapid urbanization during the last one and half decade and recoded a compound annual growth rate of 3.0% also observed compound annual growth rate is about 3.3%. Hence forth for population projections, Business as Usual (BAU) scenario is adopted and the projected populations for the next 25 years are presented in figure 3 below.

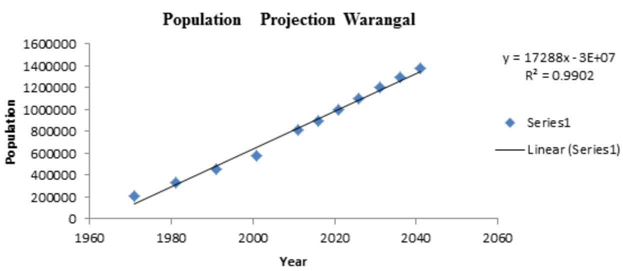

Fig.3: Population Projections of Warangal under Business as usual Scenario

Review of per capita waste generation across Indian cities reveals that it varies from 200g/capita/day to as high as 500g/capita/day. For a tier 2 city with tropical climate like Warangal, per day waste collection is recorded as 350 to 380g/person/day. Data collected during the year in the months of November to March are presented below in figure 4. Random MSW samples from 10 residential zones from the three cities Kazipet-Hanmakonda and Warangal are collected by the trained under graduate engineering students. About 300 samples were collected in polythene bags and also from the dustbins covering all cross sections of socio economic communities. Also the waste collected by the trucks is obtained from the office records of the public health engineering department. Samples of the MSW collected from dustbins at different residential zones were analyzed for their composition and aggregated physical properties of waste are presented in the table 2.

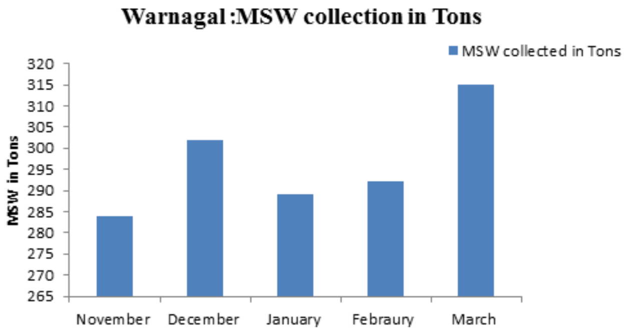

Fig.4: MSW Collected during the observation period in 2013

Table.2: Physical Properties of Municipal Solid Waste (Un Burnt Form)

Sl.No	Component Description	%(Range)
1	Organic matter	32-38
2	Paper	8-10
3	Plastic	8-15
4	Textiles	6-8
5	Gravel	4-6
6	Sand	24-32
7	Silt	8-12
8	Hard Plastic	2-4
9	Glass	1-3
10	Leather	2-4
11	Metal	2-4
12	Other	2-4
13	Wood	1-2

Among the cities one million plus population it is observed that building demolition waste and waste from new building construction activity were added significantly affecting the proportion of organic content in MSW [6]. Also from the literature review it has been observed that per capita MSW is steadily increasing among tier-I &II cities at a growth of 1.5%-2% every

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year. The reasons for increase in waste growth rate could be changing life styles, cultural habits and economic growth [10,11]

MSW projections for WMC for the next 25 years is estimated giving due considerations to, decadal population growth rates for the period 1961-2011 and growth rates in per capita MSW. While doing MSW projections an increase of 1.15% per annum was adopted as planning factor up to the year 2026 and for the rest of the period it is taken as 1.10 to take care of socio-economic and human behavioral aspects expected in the years to come. And for the years beyond 2031, the planning factor is kept as constant. The expected MSW was estimated by using equation is given below.

Expected Waste Generation = Population × Per Capita Waste Generation × Planning factor

The planning factors adopted for the MSW follows a normal distribution, which is presented in the figures 5 and 6 and in table 3.

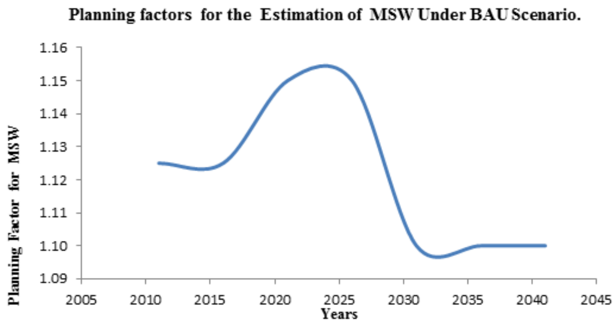

Fig.5: Planning Factors for the Projection of MSW under BAU Scenario

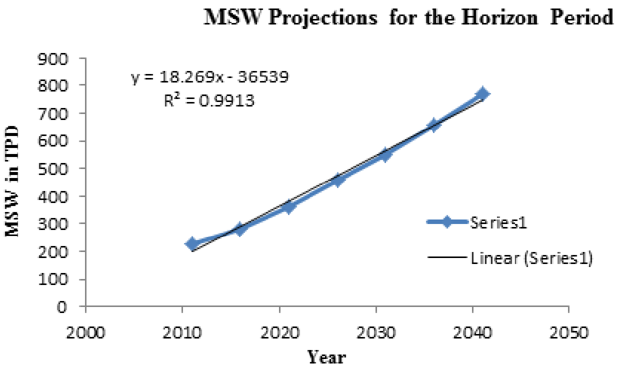

Fig.6: MSW Estimations for the horizon period in TPD

Table.3: MSW Estimations for WMC for the Horizon period under BAU Scenario

Year	Planning Factor for MSW	Per capita MSW in grams	Projected MSW in tons per day (TPD)
2001		250.00	
2011	1.13	281.25	228.33
2016	1.13	316.41	283.18
2021	1.15	363.87	362.05
2026	1.15	418.45	459.46
2031	1.10	460.29	552.35
2036	1.10	506.32	658.12
2041	1.10	556.95	767.48

V. DATA ANALYSIS

Characteristics of Burnt Municipal Solid Waste (MSW):

Drainage system in many parts of Warangal city are still continue to operate on conventional open drainage system and they are in the process of up gradation to underground system. Also it has been observed that due to inadequacy of the dust bins the solid wastes are often spilling on to the ground and the street sweeping are added to the waste. Also whenever the drains cleaned, silt is collected from the open drains are also added to the waste. Periodic maintenance of drains results in collection of waste along with silt. The collected waste from street sweepings, silt from drains being added to the dust-bins contain significant portion of silt and soils and are finally transported to the dumping yards. Thus the accumulated waste at the dumping yards contain considerable amount of soil-sand-silt.

Waste collected from the dumping yards is set for natural burning for 24 hours on open yard to ensure complete burning of organic matter and all combustible matter like plastics, rubber paper, thermo coal etc,. Ash and inert material collected after complete combustion are analyzed for their physical and engineering properties and are presented in the table 4.

Table.4: Properties of Burnt MSW Ash

Description	Percentage
Gravel Size	25-35
Sand Size	35 – 45
Silt	22 – 25

Specific Gravity of burnt waste ash: 1.56

**Gravel Size and Sand Size include metal, broken glass, demolition waste etc*

As the BMSW ash is containing about 57-70 percent of sand and silt, BMSW ash can be classified as Silty Sand(SM) and an attempt is made to assess the use of burnt waste ash in soil stabilization in presence of lime.

Burnt Municipal Solid Waste Ash in Soil Stabilization:

MSW burnt in furnace and the ash collected at the bottom of the furnace is highly puzzolonic in nature and this material is often termed as Municipal incinerated bottom ash (MIBA). Many researchers in the recent past carried

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engineering studies on MIBA for its use as highway construction material using soil stabilizing techniques. It has been reported that an yearly production of 1840 million tons of MSW is recorded worldwide [12]. MIBA is classified in to different categories based on their source of production. Using the Unified Soil Classification System (USCS), MIBA has been categorized as SW (well graded sands) [13], SM (silty sands) [14] or as SP-SM (poorly graded sand with silt) [15]. With the Association of State Highway and Transportation Officials (AASHTO) System, MIBA samples fall into the A-1 category [16, 17], which is associated with ‘‘excellent to good” subgrade rating. Non-plastic behavior has been reported for MIBA [18-20], which may benefit the material’s shear strength properties. The properties of the burnt MSW significantly depend on the burning temperature. From the ash collected from different incinerators from developed countries it is noted that the combustion temperature varies from 800° C to 1200° C. Loss on Ignition (LOI) varies from 1%-15%. According Eggenberger et al (2004) un burnt carbon in pozzolanic materials can serve as filler in the material being stabilized [21].

Ciara´n J. Lynn (2016) et.al carried study and examined data on MIBA available globally and explored the possibilities of using it in pavement component layers using stabilization technique [22]. New Delhi is producing about 7500-8000 tons of MSW and only 7% of it is treated by composting and the rest of it is going by land filling method of disposal [23]. Extensive research work was reported on use of bottom ash, demolition waste, industrial waste for their re use as construction materials using stabilization techniques [24]. The bottom ash obtained after incineration of municipal solid waste has been examined by Berg and Neal [25]; Lin et al, (2003) carried studies on burn municipal solid waste ash for its pozzolanic properties and their use in stabilizing soils [26].

Tay and Cheong (1991) observed from their laboratory investigations that municipal solid waste ash (MSWA) and can be used for partial replacement of cement as a pozzolanic material. The compressive strength of concrete mixture containing 10% MSWA has been found to be higher compared to ordinary concrete [27]

Sanewu .F, et.al (2013) carried engineering study on the pozzolanic characteristics of municipal solid waste ash (MSWA) and its use as a stabilizing agent. The authors concluded that low content of calcium oxide in MSW ash upon fine sieving can be used as stabilizing agent.[28]. Fundi I.S etal used 2% of burnt municipal solid waste ash in soil stabilization to produce earthen bricks [29].

Use of Burnt Municipal Solid Waste Ash in Local Subgrade Soil Stabilization

In this research work possibilities of using burnt solid municipal waste in stabilizing local sub grade soils in presence of lime are explored. For this the MSW collected in bulk quantity though trucks is dumped in open yard and set for burning for more than 24 hours. During open land burning of MSW it is observed that the temperature of MSW is more than 400^0 C and at this temperature the soil and silt lose their original structure and attain puzzolonic characteristics. Local sub grade soils procured from the Warangal Municipality Suburbs, near Chingatagattu village on Karim Nagar road is taken for investigation and stabilization. Engineering properties of the subgrade soil are furnished below in table 5.

Table.5: Engineering Properties of local Subgrade Soil

I **Specific Gravity of Soil**	2.65
II Grain Size Distribution	
a. Gravel	12%
b. Sand	59%
c. Fines(Silt+Caly)	29%
III Plasticity Characteristics	
a. Liquid Limit	42.44%
b. Plastic Limit	22.50%
c. Plasticity Index	20%
IV IS Classification Symbol	SC (Clayey Sand)
V Compaction Characteristics	
a. Optimum Moisture Content (OMC)	10.60%
b. Maximum Dry Density (MDD)	18.6 KN/m^3
VI Strength Characteristics	
a. Unconfined Compressive Strength (UCS)	302 kN/m^2
b. CBR	
i. Un -soaked Condition	5.12%
ii. Soaked Condition	2.80%

The optimum percentage of lime for stabilization of the soil is fixed based on unconfined compressive strength(UCS) of soil-lime-mixes at their optimum moisture contents and corresponding maximum dry densities, after 7 days of curing. The unconfined compressive strength is increasing steadily, after reaching 4% its UCS values are increasing marginally and hence an optimum value of 4 percent lime by weight of soil is fixed for stabilization. Burnt waste is added to soil lime mix at an increments of 5% and unconfined compression test specimens are prepared at respective optimum moisture contents and maximum dry densities and tested for strength after 7 day of curing. Also the soil mix samples are tested for CBR values, the optimum percentage of burnt waste on soil-lime stabilization is

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obtained as 20 percent. Engineering properties of Soil, Soil + Lime (4 percent), Soil + Lime (4 percent) + Burnt waste (20 percent) are given in Table 6. Also the improvement in CBR and UCS upon stabilization of subgrade soil is explained in figures 7-10

Table.6: Properties of Soil + Lime (4%) + Burnt Waste (12%) Mixes

Engineering Property	Soil + Lime (4%)	Soil + Lime (4%) + Burnt Waste (12%)
Compaction Characteristics a. OMC b. MDD	 11.4 % 1.92 T/m^3	 12.12 % 1.94 T/m^3
Strength Characteristics (After 7 Days of Curing) a. UCS b. CBR	 692 kN/m^2 6.9%	 1412 kN/m^2 14.8 %

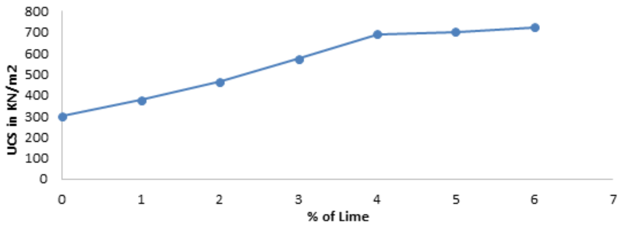

Fig.7: Variation of UCS (7 Day) on Subgrade Soil stabilization at different lime %

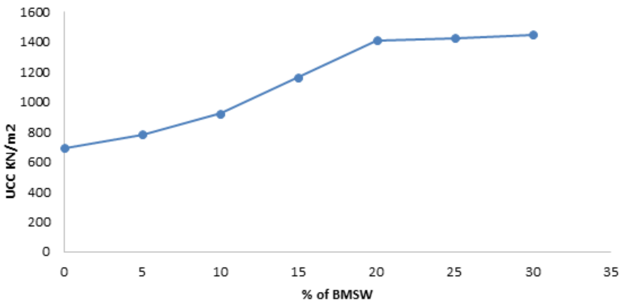

Fig.8: Variation of UCS (7 Day) on Lime (4%) stabilized Subgrade Soil at different BMSW %

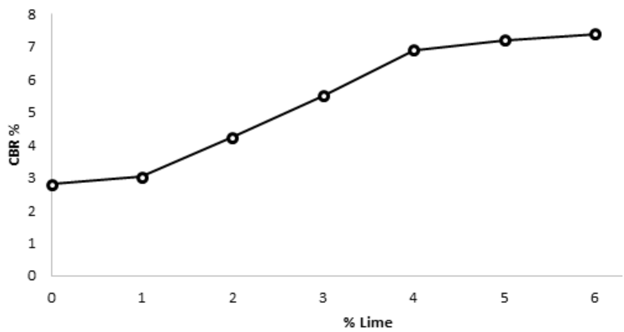

Fig.9: Variation of CBR on Subgrade Soil at different lime %

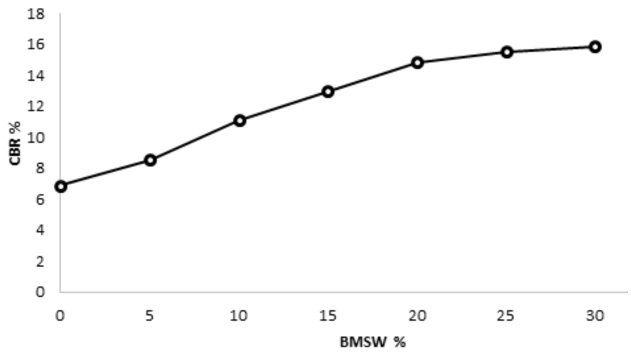

Fig.10: Variation of CBR on Lime stabilized Subgrade Soil at different BMSW %

Use of BMSW Ash in Subgrade Soil Stabilization and its effect on Pavement Thickness:

From the experimental investigations it is revealed that, BMSW can be used in subgrade soil stabilization to improve its strength properties. From the laboratory investigations it is revealed that at 4% of lime stabilization the CBR value of the subgrade soil has been increased from 2.8% to 6.9% and further stabilization with BMSW at 20% its CBR has been increased up to 14.8%. Reduction in flexible overlay thickness has been examined for low traffic volumes for which a traffic factor of 10 MSA is examined. Pavement overlay thickness requirements using IRC37 (2001) charts [30] is estimated and given in the table 7.

Table.7: Pavement overlay thickness with and without stabilization

Assumed Traffic Factor (Low)	Soil Description	CBR	Thickness of Pavement Over Lay mm	Reduction in Thickness
10 MSA	Original Soil	2.80%	750	
	Soil + 4% lime	6.90%	580	23%
	Soil + 4% lime + 20% BMSW	14.80%	500	33%

From the table it can be seen that by using BMSW as stabilizing agent in presence of lime a significant reduction (33%) in over lay thickness can be achieved.

VI. CONCLUSIONS

- Solid Waste /management have to be treated as an integrated activity involving multi – disciplinary specialist/ specializations.

- In Warangal Municipal Corporation the generation of residential waste is more than 250 Tons per day with a per capita generation of 300-400g per day.
- As the municipal solid waste is found to contain about 30-36 percent organic matter, the present method of on land disposal requires longer period for complete decomposition and consolidation apart from causing environmental pollution. Also as the MSW contains up to 40% of soil and silt by weight , these soil can be recovered after burning
- The leachate produced from decomposing waste from dumping yards may cause pollution of soil as well as underground water. Hence On land burning of dumped waste is suggested.
- The burning of dumped waste increases the capacity of dumping yard as the volume of organic matter gets reduced significantly after burning.
- During burning of the MSW at the site the temperature would reach more than 350^0-400^0C, and the ash and silt content attain puzzolonic characteristics and can e be sued in stabilization of subgrade soils.
- Many Tier –II and III cities are planning to adopt incineration method of disposal for MSW. Burning of MSW in incinerator produces large quantities of Municipal incinerated bottom ash (MIBA). As this MIBA is highly puzzolonic in nature, there is a need for its use in road construction to conserve the natural resources.
- The study carried in is only for demonstrative purpose to investigate use of BMSW ash in local soil stabilization. Properties of BMSW ash vary marginally from sources to source. Also the percentages of stabilizing agents vary from soil to soil. However for large scale stabilization-practical applications, chemical properties of BMSW ash need to be established through x-ray diffraction and also the role of BMSW ash in strength contribution need to be established scientifically.

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