Geotechnical Properties of Lime and CKD admixed Bio-solids

Prathap Kumar M T [1], Karthik N[2], Basavalinga[3], Annappa Hemanth M N[4] and Nagesh Kumar D R[5]

[1] Professor and Head, Department of Civil Engineering, RNS institute of Technology, Bengaluru-560098, Karnataka, India
[2,3,4,and 5] UG Students, Department of Civil Engineering, RNS institute of Technology, Bengaluru-560098, Karnataka, India
[1]drmtprathap@gmail.com, [2]karthik.nkarthik.n07@gmail.com, [3]bassugopali@gmail.com,[4]annappa.hemu@gmail.com, [5]nageshkumardr426@gmail.com

Abstract. The amount of waste generated due to impact of urbanization has increased worldwide. To evolve sustainable use of materials, it is imperative to use treated waste materials as a good step in waste management. The objective of present investigation is to verify the improvement in geotechnical properties of biosolids which is one of the waste materials generated from wastewater treatment plant. In the present study, the biosolid was admixed with different percentage of lime. The optimum lime content (OLC) was determined based on compaction characteristics. To further improve its geotechnical properties, cement kiln dust (CKD) was added along with OLC and various geotechnical properties were determined. It was found that, the blended bio-solids with 20% OLC along with 10% CKD showed significant improvement reduction in liquid limit, increase in shear strength and CBR, indicting its potential application as a subbase material in road construction.

Keywords: bio-solids, cement kiln dust, optimum lime content.

1 Introduction

Sludge formed in the sewage treatment plants are the unavoidable results of treating the domestic sewage and industrial effluent. Failure to regularly remove the sludge from the sewage treatment results in the work failing, having an adverse effect on receiving watercourse. Management of the sludge requires a secure outlet. Increasing legislation and environmental pressures on conventional sludge disposal has led to the high-tech sludge processing and treatment solutions throughout in the world. The production of large number of biosolids generated during the treatment of wastewater presents an enormous challenge. Historically, biosolids have been disposed using practices such as ocean disposal, landfill and incineration. These options are becoming less viable due to stricter environmental regulations and the economic cost associated with these disposal options. More recently, options for the use of biosolids for beneficial purpose have been explored. Biosolids are rich in organic matter and nutrients, and therefore land application has been advocated as a sustainable option for resource recovery. In many advanced countries, biosolids have been used for land application in agriculture (vine, cereal, pasture, olive), co-generation/power production/energy recovery and Road base. Some of the recent studies have explored use of stabilized biosolids for many infrastructure applications. Biosolids are rich in both organic matter and essential plant nutrients and can be utilized in a variety of ways, directly as a soil amendment and fertilizer and failure to regularly remove the sludges from the sewage treatment works has an adverse effect on the receiving watercourse [1]. It has been investigated that the addition of biosolid and lime sludge undermines the strength of landfill and has been found that landfilling biosolids offers competitive cost and in fact, is cheaper than some alternative disposal option [2]. The effects of untreated biosolids if used for agricultural activities transmit many pollutants to environment and create many hazards for public health. However, addition of lime to stabilize biosolids reduce the fecal coliforms more than 99.99% and hence can be used for reconditioning the poor soil and are for covering of solid waste landfill site [3 and 10]. Several field and laboratory studies have been reported in literature to assess the geotechnical properties of biosolids and viability of using biosolids as stabilized fill for road embankments [4,5 and 6]. Review of several literatures have indicated beneficial uses of cement kiln dust (CKD), which is a by-product waste material of the cement manufacturing process. Because of high lime and potassium concentration CKD can be used as a soil amendment or fertilizer. Use of CKD in stabilizing biosolids results in reduction of concentrations of heavy metals within acceptable international limits [7,8and 9]. Tests conducted on poor soil conditions using CKD as stabilizer results in inadequate strength and bearing capacity of soil. Further, native soil properties like compaction characteristics, plasticity, CBR and permeability can be improved using CKD. However, use of CKD as a stabilizer for assessing geotechnical properties of biosolids is scarce in literature. The objective the present study is to assess geotechnical properties of biosolids stabilized with optimum lime content as well as cement kiln dust (CKD). Lime is a well-known stabilizer for many expansive soils and hence suitable for stabilizing biosolids in terms of reduction in volume change capability of biosolids. Hence, along with lime, CKD has capability to induce better cementation and hence increase strength of stabilized biosolids making it suitable for pavement subbase applications. A laboratory investigation of stabilized biosolids using optimum lime and CKD content was conducted and geotechnical properties of biosolids was assessed in terms of plasticity, shear strength in terms of curing period and its possible applications as a subbase material has been assessed in terms of CBR.

2 Materials and Methods

2.1 Materials Used

Biosolids Used: For the present study the biosolids was procured from wastewater treatment plant located at Mylsandra, Kengeri, Bengaluru which has a capacity of treating 75 megalitres per day (MLD). Chemical analysis of biosolids indicated presence of Arsenic, Cadmium, Copper, Iron, Magnesium, Lead and other heavy metals within permissible hazardous limits. Table 1 summarizes index properties of biosolids determined in the laboratory. Fig.1 shows XRD analysis of biosolids alone that indicates peak occurring at 2θ in the range of 25^0-27^0 indicating the presence of bentonite and low quartz.

Table 1. Index Properties of biosolids

Sl. No	Particulars	Value
1	**Grain size analysis**	
	% of gravel	0
	%of sand	82
	% of silt	17
	% of clay	1
2	Specific gravity	1.62
3	**Plasticity properties**	
	Liquid Limit (LL) percentage	104
	Plastic Limit (PL) percentage: Not possible to roll	
4	**Compaction Characteristics (Heavy compaction test)**	
	Maximum dry density kN/m^3	8.25
	Optimum moisture content percentage	57
5	P^H value	6.85
6	Organic content in % (LOI Test)	43

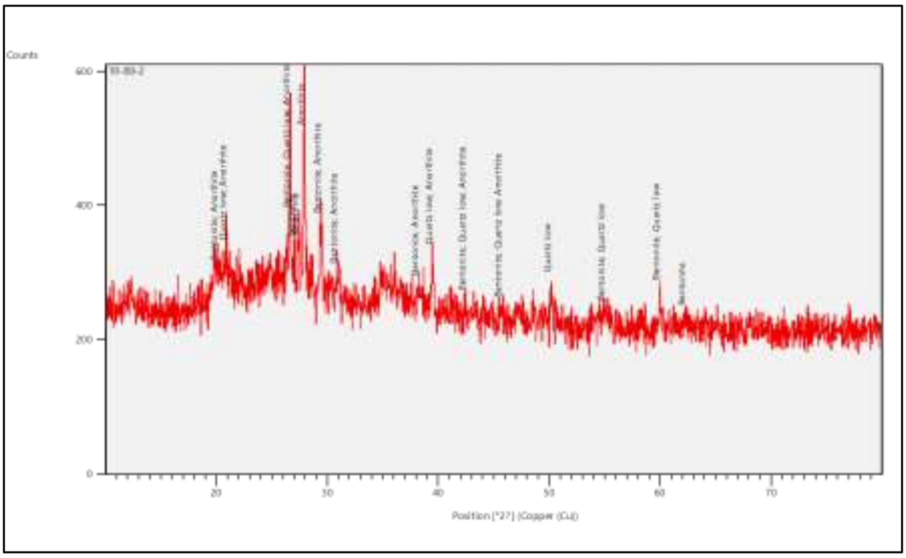


Fig. 1 XRD analysis of biosolids alone

Hydrated Lime: Class F hydrated lime ($CaOH_2$) is used in the present study which was procured from *SD Fine-Chemicals Limited; Mumbai*, India. The chemical analysis and constituent of hydrated lime ($CaOH_2$) used in the present investigation indicated the presence of CaO at around 85percentage by mass of lime used.

Cement Kiln Dust: The Cement kiln dust brought from the ACC cement production plant, which is placed at Wadi of Gulbarga district, Karnataka, India. Chemical analysis of CKD indicated greater absorption of alkalies and chloride which is useful for biosolid stabilization. The sulphate content lies within the acceptable limits with CaO at around 49.3% by weight.

2.2 Methodology

Optimum lime content and optimum CKD along with lime was determined based on heavy compaction test by mixing lime alone to biosolids in percentages varying from 5,10,15,20 and 25% and CKD along with optimum lime content in percentage varying from 5,10 and 20%. The optimum percentage was thus determined based on maximum dry density (MDD) with minimum optimum moisture content (OMC).

Shear strength of biosolids alone, stabilized biosolids using optimum lime as well as optimum lime and CKD was conducted using direct shear test on remolded specimen. The remolded specimen was prepared using corresponding MDD and OMC obtained from compaction test for respective configuration used in the present study. The effect of curing was studies by keeping the prepared remolded specimen in plastic cover and kept in desiccator for 0,7,14 and 28 days. CBR test as biosolids alone and stabilized biosolids for optimum configuration obtained based on shear strength test in 4 days-soaked condition after curing the specimen for a period of 24 hours with optimum lime and CKD content to assess various geotechnical properties and arrive at conclusions on its suitability as a subbase material.

3 Results and Discussions

3.1 Determination of Optimum Lime Content (OLC) and CKD

Maximum dry density (MDD) and corresponding Optimum lime Content (OMC) was obtained using heavy compaction test on biosolids alone and by adding lime varying from5,10,15,20 and 25%. The OLC was arrived at based on the maximum value of MDD and corresponding minimum value of OMC as shown in Fig. 2. It was found that biosolids mixed with 20% lime content is found to be optimum. Using the OLC thus obtained, biosolids mixed with 20% OLC was further mixed with different percentage of CKD varying from 5,10, 15 and 20%.

As shown in Fig. 3, it was found that 10% CKD was optimum when it is used in conjunction with biosolids plus 20% OLC. Table 2 summarizes the values of MDD, and OMC obtained at OLC and optimum CKD obtained for biosolids admixed with OLC.

Table 2 Summarized values of maximum MDD and minimum OMC of biosolids admixed with lime and CKD

Particulars	MDD kN/m^3	OMC (%)
Biosolids alone	8.17	57
Biosolids+20percentageLime	9.09	40
Biosolids+20percentageLime+10percentageCKD	9.96	47.7

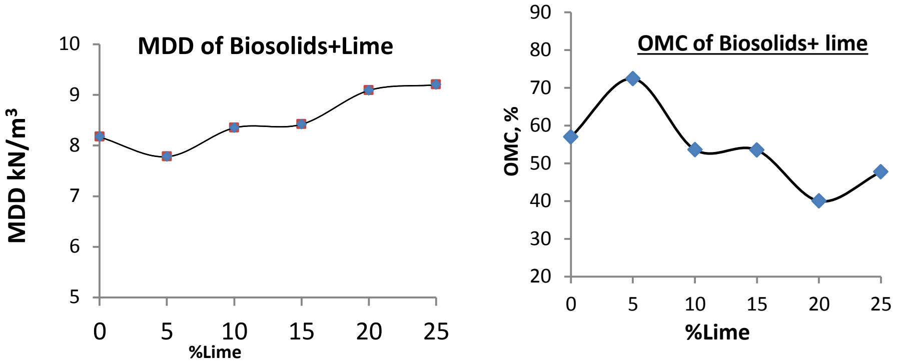


Fig. 2 Variation of MDD and OMC for Biosolids +Lime

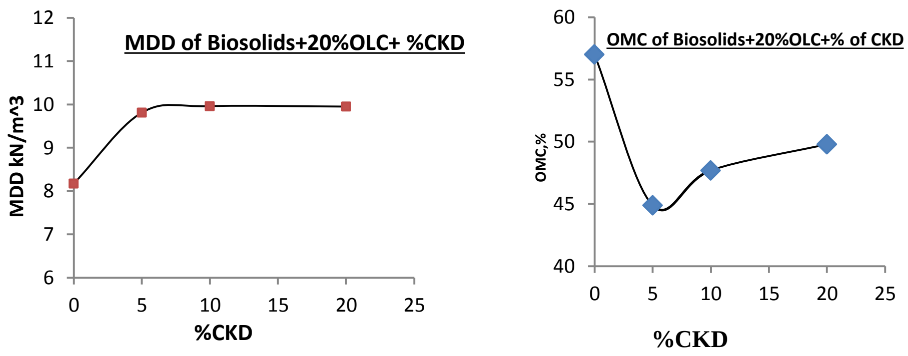
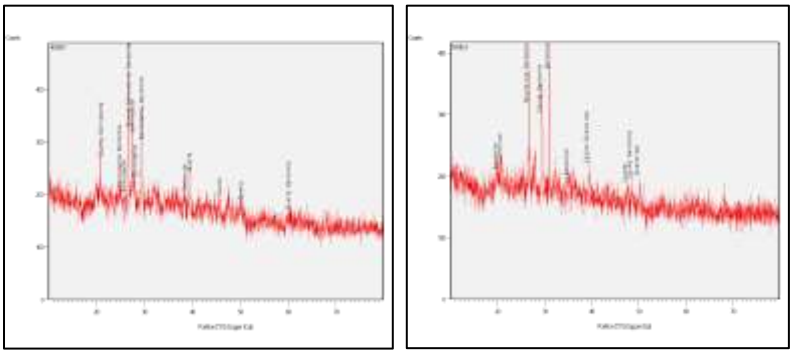


Fig.3 Variation of MDD and OMC for Biosolids+20%OLC+5%CKD

3.2 Effect of OLC and CKD on Shear strength characteristics of Biosolids

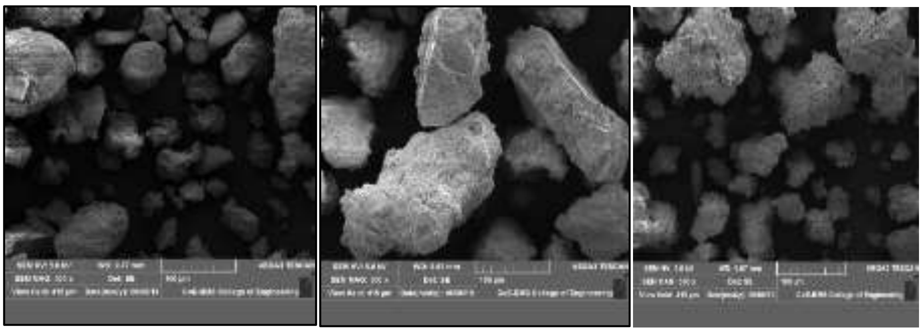
Fig.4(a) shows XRD of biosolids admixed with 20%OLC which indicated peak in the range of 2θ equal to 27^0-28^0 degree with presence of calcium oxide. Presence of CaO assist pozzolanic reaction and also causes agglomeration of particles. Fig. 4(b) shows XRD of biosolids + 20%OLC+ 10% CKD which indicated several peaks in the range of 2θ equal to 26^0-32^0.The peaks indicates the formation of calcite with low quartz and hence better cementation, due to addition of CKD in combination with lime.

Figure 5 shows microstructural changes observed in particles of biosolids in comparison to biosolids admixed with OLC as well as biosolids admixed with 20% OLC+10% CKD at magnification of 500x Particles of biosolids are rounded and small whereas particles of biosolids +20%OLC indicate larger particles that are rough textured, which assist denser packing leading to higher compaction obtained in the experimental results. White patches indicate that the particles are coated with calcium ions. Addition of both optimum lime and CKD makes particles of biosolids coarser and more angular, and white patches around the particles indicates presence of calcite. These structural changes, hence, leads to better compaction that leads to increase in shear strength and reduction in liquid limit, since stabilization with lime and CKD has resulted into stable particulate matter suitable for many civil engineering applications such as road works and embankments.



(a) Biosolids+20%OLC (b) Biosolids+20%OLC+10%CKD

Fig.4 XRD analysis of biosolids stabilized with OLC and CKD



(a)Biosolids alone (b) Biosolids+20%Lime (c) Biosolids+20%OLC+10%CKD

Fig 5 SEM images of Biosolids alone, and stabilized biosolids with OLC and CKD

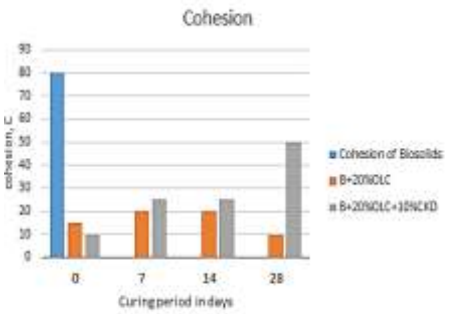
Table 3 summarizes the values of liquid limit with the addition of optimum lime and CKD. Since the particle size analysis of biosolids indicated at around 82% sand sized particles, it was not possible to roll it to threads smaller than 5mm and hence lacks plasticity. Further, addition of OLC reduces liquid limit and addition of CKD along with OLC causes further reduction li liquid limit which is desirable in many civil engineering applications.

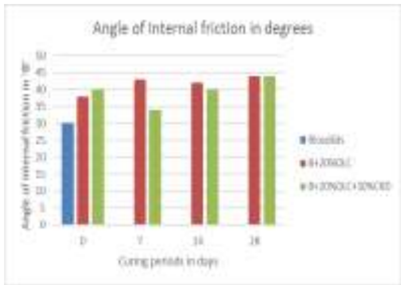
Table3 Variation of LL of stabilized biosolids

Particulars	LL (%)	PL (%)
Biosolids alone	104	Not possible to roll
Biosolids+20%OLC	81.5	Not possible to roll
Biosolids+20%OLC+10%CKD	68	Not possible to roll

Since the compacted density of remolded specimens of biosolids alone and stabilized biosolids with OLC and CKD falls in the range of 8.17 to 9.96 kN/m^3, direct shear test was performed by remolding the specimens directly in the shear box and shear strength parameters were evaluated in terms of effect of curing period by conducting undrained shear strength test. The specimens were mixed with OLC and OLC+CKD and cured in a desiccator by keeping the specimens in a plastic cover for a period of 0,7,14 and 28 days. The specimens were then remolded in the shear box corresponding to the MDD and OMC obtained from compaction test.

Fig.6(a) and (b) shows variation of shear strength parameters 'Cohesion, c in kN/m^2 and angle of internal friction, Φ in degrees' in terms of curing period obtained from direct shear test on stabilized biosolids in comparison with biosolids alone. Fig 6(a) shows addition of lime decreases significantly the cohesion of biosolids. However, with increase in curing period and addition of CKD, cohesion increases marginally at 7 and 14 days and significantly at 28days curing. This is because, addition of CKD increases availability of calcium cations causing significant base exchange and hence induces better cementation than lime alone, as evidenced in XRD and SEM analysis presented earlier. Fig.6(b) shows similar such variation of Φ with curing period. In the initial stages of addition of lime as well as , Φ value increases with in curing period. Further there is consequent reduction in Φ values. It can be attributed to the fact that introduction of finer CKD particle increases surface area and with increase in curing period better cementation and hence reduction in Φ. However at 28days curing it seem to attain equilibrium indicating almost same value of Φ due to completion of pozzolanic reaction. XRD analysis and micro structural changes presented in SEM images have substantial evidence in corroborating the trend in variation of shear strength. The overall trend thus indicates increase in shear strength due to addition of lime and well as addition of CKD which is necessary for biosolids to be used as a construction material in many applications in the field of civil engineering.





(a) Variation of Cohesion (b) Variation of Angle of Internal Friction

Fig.6 Variation of Shear Strength Parameters of Stabilized Biosolids

3.2 CBR of Stabilized Biosolids

Road work constructions demand use of large quantities of construction materials such as aggregate and filled materials. Use of stabilized biosolids in road work applications can significantly affect the economy of road construction. The result on stabilized biosolids has clearly indicated increase in density of compaction, decrease in liquid limit as well as increase in shear strength. In order to verify the applicability of biosolids in road work application, soaked CBR test was conducted by compacting the biosolids along with OLC and OLC+CKD at respective MDD and OMC. The biosolids mixed with lime as well as CKD was cured for 7 days and then soaked for four days before the CBR test was done. The CBR value was comparatively assessed with respect CBR value obtained for biosolids alone. The CBR at 2.5 and 5mm penetration was used for comparison purpose. Table-4 shows comparative variation of CBR of stabilized biosolids admixed with lime as well as lime + CKD. CBR of biosolids stabilized with OLC have indicated at around 280% increase in CBR. Further biosolids admixed with 20%OLC+10%CKD have indicated an increase of around 170% in the measured values of CBR. Thus, the results indicate that the stabilized biosolids have soaked CBR value in excess of 4% which is desirable and enough to recommend its use as a subbase material with a potential to, being be used in road work based on material performance measures.

Table 4: Summarized CBR values of Stabilized Biosolids

Particulars	CBR(Soaked)	
	CBR at 2.5 mm	CBR at 5 mm
Biosolids alone	1.52	1.82
Biosolids+20percentageLime	5.83	5.23
Biosol-ids+20percentageLime+10percentageCKD	4.11	4.36

4 Conclusions

On the basis pf present experimental study on stabilized biosolids with OLC and CKD the following major conclusions have been drawn:

- Addition of lime increases dry density and decreases optimum moisture content. However, the MDD of biosolids alone was found to be 8.17kN/m^3 at OMC of 57percentage. The values of both bulk and dry density obtained in the compaction test were low due to low particle density of the biosolids.
- SEM studies indicated presence of calcium ions in both lime as well as CKD that induces cementation and makes particles to agglomerate resulting in the reduction of available surface area, contributing to denser packing of the admixture.
- The structural changes due to the addition of both lime and CKD making particles of biosolids more coarser and angular assists compaction, increases shear strength, reduces liquid limit with a consequent increase in CBR making biosolids more stable to be used for many civil engineering applications such as road works and embankments.
- A reduction of 21.6percentage in LL occurs due to addition of optimum lime and around 35percentage reduction in LL occurs due to addition of optimum lime along with optimum CKD.
- Addition of both lime as well as lime + CKD reduces cohesion with consequent increase in angle of internal friction due to the transformation of particles into angular and large sized, due to addition of lime as well as CKD.
- Increase in curing period with addition of CKD increases cohesion at 7 and 14 days marginally and significantly at 28days curing. Additional availability of calcium cations from CKD causes significant base exchange CKD, inducing better cementation than lime alone. At 28days curing, Φ value seem to attain equilibrium indicating completion of pozzolanic reaction.
- Comparative variation of CBR of stabilized biosolids admixed with lime as well as lime + CKD. indicated at around 280% increase in CBR due to addition of lime alone. Further biosolids admixed with 20%OLC +10% CKD have indicated that an increase of around 170% in the measured values of CBR. The results suggest that stabilized biosolids have the potential to be used in road work based on material perform measures.

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