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A PRELIMINARY INVESTIGATION ON THE GEOTECHNICAL PROPERTIES OF BLENDED SOLID WASTES AS SYNTHETIC FILL MATERIAL

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ABSTRACT

This study investigated the possibility of developing a synthetic fill material by combining industrial waste materials, thus, integrating the properties of cohesion and friction as a replacement for natural soil. Biosolids and steel slag were selected for proportioning of the synthetic fill material. They were blended in different proportions and the geotechnical properties of the various blends were investigated to determine the strength and bearing of the blended synthetic material for fill applications. The results of the investigation were encouraging with the index properties of the blends better than those of biosolids. It was found that 25% to 40% steel slag blending produced the maximum strength and bearing. The investigation revealed that blending of industrial waste materials has the potential to perform the function of a synthetic fill material in road embankments and backfills. However, further studies are recommended to investigate its long term compressibility and permeability and further improvement of bearing to meet local standards.

Keywords: Biosolids; Blending; Embankment; Slag steel; Synthetic fill material

1. INTRODUCTION

With the advancement of civilization, human dependency on natural resources has increased several fold, resulting in overexploitation of resources. This has exerted severe strain on the natural resources. Soil is one such natural resource whose application in recent civil engineering works is enormous. Soil is heavily consumed, be it as a fill material in embankments, retaining walls or other construction activities or as a raw material for mortar, concrete, blocks, bricks etc. There is an urgent need to develop alternative materials to be used as a replacement in order to reduce the pressure on utilization of soil. One method of developing an alternative is to modify materials which have properties similar to natural soil. Several industrial activities result in huge quantities of waste materials as by-products that have resulted in disposal problems. There have been several efforts to habituate such materials in soil engineering in order to improve their utilization. Industrial wastes have been used in soil stabilization successfully for the effective utilization of poor soils. Industrial wastes like Fly Ash (Mishra, 2012; Mccarthy et al., 2014), Rice husk ash (Osinubi et al., 2012; James et al., 2014) Phosphogypsum (Krishnan et al., 2014; James & Pandian, 2014), Ground granulated blast furnace slag (Obuzor et al., 2012;

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Celik & Nalbantoglu, 2013), Bagasse ash (Lima et al., 2012; James & Pandian, 2016), Cement kiln dust (Hossain, 2011; Moses & Saminu, 2012), Ceramic waste (Sabat, 2012; James & Pandian, 2017), red mud (Gray et al., 2006; James & Pandian, 2016), steel slag (Shen et al., 2009; Yildirim et al., 2013) have been used in soil stabilization successfully for the effective utilization of poor soils. Such stabilized soils can be used in numerous applications like road embankments and backfills, nevertheless, though natural soil still forms the core of the stabilized material used for civil engineering applications. In this study, proportioning an artificial fill material as a substitute for natural soil has been attempted. The strength of any soil is, in general, characterized by its shear strength parameters viz., Cohesion (c) and Angle of internal friction (φ). With this concept as base, this study aims at developing synthetic fill that exhibits these properties. Biosolids and coal by-products have the property of cohesion, whereas steel slag, quarry waste and crushed glass provide frictional characteristics to a soil. A number of previous works have attempted and reported on the characteristics of biosolids in an effort to understand its behaviour. Arulrajah et al. (2011) studied select chemical and engineering properties of waste water biosolids. Arulrajah et al. (2013) studied the geotechnical properties of wastewater biosolids for application in road embankments. O'Kelly studied the mechanical, geotechnical and consolidation properties of sewage sludge (O'Kelly, 2005; 2006; 2008). Chen et al. (2014) investigated the shear strength and permeability characteristics of dewatered sewage sludge. Puppala et al. (2011) examined the quality of run-off leachate collected from biosolids amended topsoil. Arulrajah et al. (2013) had concluded that though compacted biosolids exhibited good shear strength, it cannot be considered as a good geotechnical fill material on its own due to high deformation under applied loads in both short term and long term performance. Hence, they suggested that the soil thus developed needs to be stabilized or blended with a high-quality material to improve its geotechnical performance. There are also studies on the stabilization of biosolids for improving its properties. Samaras et al. (2008) studied the stabilization potential of fly ash and lime on biosolids. Li et al. (2014) utilized fly ash with quick lime and ferric chloride for stabilization of sewage sludge. Suthagaran et al. (2008) used cement for stabilization of biosolids. Lin et al. (2013) identified cost effectiveness when cement along with additives calcium bentonite, fly ash and kaolinite are combined in the stabilization of sewage sludge. Wang et al. (2014) used mussel shells for stabilization of biosolids. Li et al. (2007) adopted a novel method of using nano-zero valent iron particles for stabilization of biosolids. There have also been investigations based on the latter method of blending biosolids with high quality material. Asakura et al. (2009) recycled slag and construction and demolition waste by blending with biosolids in order to improve its permeability. Disfani et al. (2009) blended fine recycled glass with biosolids to improve its strength characteristics. Wanigaratne & Udamulla (2012) used crushed bricks for improving the properties of biosolids. Kayser et al. (2011) used fly ash, lime kiln dust, two types of slag as well as construction debris in improving biosolids. In this study, the latter approach of blending industrial wastes, has been adopted. A combination of biosolids and steel slag has been studied in order to achieve a proportioned synthetic fill and its geotechnical properties have been investigated to gauge its performance. This work was conceived with the idea of developing a synthetic replacement for soil in fill applications rather than stabilizing biosolids. Earlier investigations revealed that biosolids are not suitable as a fill material due to its poor geotechnical properties. Thus, the principle behind adopting steel slag was to not only improve biosolids, but also to develop an artificial soil like material having the properties of cohesion and friction. With the rapid pace of infrastructure development, successful optimization of biosolids and steel slag in generating a synthetic fill can hugely contribute to the effective management of these solid wastes, while being a cheap construction material for construction of subgrades, embankments for roads and railways, back fills for retaining walls, foundation backfill, floor fills in buildings and ground level elevations. Steel slag can not only act as a coarse-grained filler in the amended biosolids but also can act as a mild stabilizer depending upon the availability of free lime. Thus, the primary objective of this investigation is to study the strength and bearing of biosolids-steel slag combination as a viable alternative to soil in fill applications.

2. MATERIALS AND METHODS

The materials that were used in this study include biosolids, used as a cohesive component and steel slag used as a friction component for the proportioning of a synthetic fill material. The biosolids and steel slag used for the study were sourced from Koyambedu Sewage Treatment Plant, Chennai and a rebar manufacturer in Gummidipoondi, Tamilnadu, India, respectively.

2.1. Biosolids

Biosolids refers to dried sludge having the characteristics of a solid typically containing 50–70% by weight of oven dried solids. Sludge refers to solid–water mixture pumped from wastewater treatment lagoons having the characteristics of a liquid or slurry typically containing 2–15% of oven dried solids (Arulrajah et al., 2011). While the term “biosolids” is often used interchangeably with “sewage sludge”, the USEPA (2003) considers biosolids to be sewage sludge that has been treated to meet state and federal standards for beneficial use. Lo et al. (2002) state that stockpiled biosolids can be considered as a geotechnical material similar to non-consolidated cohesive soils with high organic content. Biosolids have applications as fertilizers and soil amendments, energy recovery and in construction materials (Wang et al., 2008). However, a number of researchers have gone into the reuse of biosolids as geotechnical fills recently. Arulrajah et al. explored the geotechnical properties of wastewater biosolids to assess its appropriateness as structural fill in road embankments (Arulrajah et al. 2011; 2013). Intharasombat et al. (2007) studied the application of biosolids compost in mitigation of highway shoulder desiccation cracks. Suthagaran et al. (2008) examined untreated as well as stabilized biosolids as a fill material for engineered fills. Wanigaratne & Udamulla (2012) also investigated the ability of stabilized biosolids as embankment fill material. Laboratory tests were done on the collected biosolids samples and the properties determined are listed in Table 1.

Table 1 Properties of biosolids

Property	Value	Property	Value
Liquid Limit (%)	63	Unconfined Compressive (UCC) Strength (kPa)	22.76
Plastic Limit (%)	51.8	Unsoaked California Bearing Ratio (CBR) (%)	1.8
Shrinkage Limit (%)	10.3	Gravel size fractions (%)	0.47
Plasticity Index (%)	11.28	Sand size fractions (%)	17.95
Specific Gravity	2.15	Silt size fractions (%)	62.36
Optimum Moisture Content (OMC) (%)	52.5	Clay size fractions (%)	19.22
Maximum Dry Density (MDD) (kN/m^3)	8.63	Classification	OH

2.2. Steel Slag

Steel slag is a by-product resulting from the manufacturing process of steel. It is obtained during the separation of molten steel from the impurities in the furnace in liquid state. It is a complex solution of silicates and oxides, which solidifies into steel slag on cooling. Huang and Lin (2010) reported the following composition for the steel slag used in their investigation: Silica–16.63%, Alumina–7.0%, Iron oxide–18.90%, Calcium oxide–38.50% and Magnesium oxide–9.42%, whereas Grubb et al. (2011) reported the following figures: Silica–10.65%, Alumina–4.09%, Iron oxide–26.84%, Calcium oxide–37.21% and Magnesium oxide–10.31%.

However, the results of both agree with each other with respect to the fact that major components of steel slag are silica, alumina, iron oxide, calcium oxide and magnesium oxide. Al-Rawas et al. (2002) also state that steel slag consists mainly of calcium, iron, unslaked lime, and magnesium. Steel slags have been used very effectively in civil engineering applications, in situations like manufacture of cement (Huang & Lin, 2010), road base material (Shen et al., 2009), immobilization of heavy metals (Grubb et al., 2011) and soil improvement (Liang et al., 2012). Steel slag is capable of replacing sand due to the granular nature of the particles on crushing. This is evident from the investigation carried out by Chen et al. (2007) in adopting steel slag as fine aggregate in lieu of sand in mortars. Liang et al. (2012) noticed an increase in the friction angle of clayey soil with an increase in steel slag and water content. Thus, steel slag can be used effectively as a friction contributor in the synthetic fill. The specific gravity of steel slag tested in the laboratory resulted in a value of 2.68 which is in agreement with value of 2.85 reported by Chen et al. (2007) whereas Grubb et al. (2011) and Akinwumi (2014) reported the same as 3.27 and 3.58, respectively.

2.3. Methods

Biosolids sample obtained from the sewage treatment plant was wet, hence it was first air dried in the laboratory followed by oven drying for a period of 24 hours. The dried sample was then crushed and pulverized to break up the lumps and clods as per the procedure stipulated in the Bureau of Indian Standards (BIS, 1983) for the preparation of any soil sample. The properties of biosolids were determined in the laboratory and classified as organic soil of high plasticity (OH) as per BIS (1970) (Table 1). Steel slag obtained from the mill was crushed using a hammer into smaller particles and then sieved using BIS sieves of sizes 2.36 mm, 1.18 mm, 0.7 mm, 0.6 mm, 0.425 mm, 0.3 mm and 0.15 mm, respectively. The particle sizes considered in the study were between 2.36 mm and 0.15 mm. Particles coarser than 2.36 mm resulted in difficulty in handling of the material. Since steel slag is used for imparting frictional property, the fines (fine aggregates) smaller than 0.15 mm were removed from the proportioning. In order to reduce the variability of the mix, the particles of steel slag retained on the various sieves were taken in equal weights to achieve the final slag sample adopted for blending with biosolids. The biosolids and steel slag were mixed together by selecting the following combinations: biosolids to steel slag ratios mixed in proportions of 75:25, 50:50 and 60:40, respectively. In order to further increase accuracy of results, three samples per mix were tested and the average of the triplicates has been reported. Disfani et al. (2009) adopted ratios starting from 90:10 to 10:90 for a glass-biosolids mix. The ratio of 25:75 was not considered as a higher composition of steel slag in the mix resulted in difficulty in performing Atterberg limits tests. The different combinations were then tested for their properties in order to evaluate the performance of each mix. Various tests were performed, including Liquid Limit and Plastic Limit (BIS, 1985b), Shrinkage Limit (BIS, 1972), Specific Gravity (BIS, 1980b), Grain Size Distribution (BIS, 1985a), Proctor Compaction (BIS, 1980a), UCC Strength (BIS, 1991) and CBR (BIS, 1987) in accordance with BIS.

3. RESULTS AND DISCUSSION

Biosolids are materials similar to non-consolidated cohesive soils with high organic content. Its geotechnical properties were modified by blending it with steel slag in various proportions. The tests on blending show encouraging results. The variations in properties of the blends have been discussed in the following sections.

3.1. Effect of Steel Slag on Specific Gravity and Atterberg Limits

Figure 1a shows the variation of specific gravity of biosolids with increasing blending ratio of steel slag. It can be observed that the addition of steel slag has resulted in an increase in the specific gravity of the mix. The specific gravity of biosolids is 2.15 as against the values of 1.66

(Kayser et al., 2011), 1.75-1.79 (Arulrajah et al., 2013) and 1.93 (Wanigaratne & Udamulla, 2012) stated by earlier researchers. At a mix ratio of 50:50 (biosolids to steel slag), the specific gravity increased to 2.37. This may be attributed to the increasing content of steel slag whose specific gravity is higher than biosolids. Akinwumi (2014) also reported an increase in the specific gravity of soil when modified with steel slag.

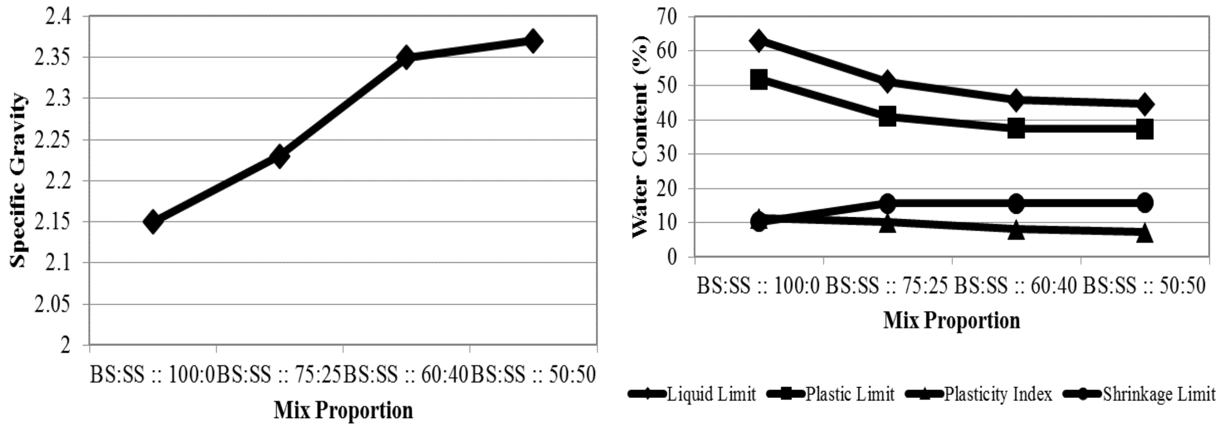

Figure 1 Variation of: (a) specific gravity; and (b) Atterberg limits of different blends

Figure 1b shows the variation of liquid limit, plastic limit, plasticity index and shrinkage limit of biosolids with increasing steel slag content. Increasing the proportions of steel slag in biosolids have resulted in reduction in liquid limits of the blends. The liquid limit of biosolids was 63%. Previous investigators had reported significantly high values of liquid limit, 100-110% (Arulrajah et al., 2011; 2013), 315% (O'Kelly, 2005) and even up to 666% (Kayser et al., 2011). However, a value of 79.8% reported by Wanigaratne and Udamulla (2012) was much closer to the value reported in this work. With the addition of steel slag, the liquid limit reduced to 44.52 % for 50:50 ratio of biosolids to steel slag. The increase in non-cohesive content of steel slag has resulted in a decrease in the liquid limit of the blend, indirectly indicating an improvement in the compressibility characteristics of the blend. The plastic limit of biosolids reduced from 51.8% to 37.26% for 50:50 ratio. Arulrajah et al. (2011; 2013) had reported a plastic limit of 79-83%, whereas O'Kelly (2005) had reported it as 55% which was more in agreement with the present study. However, Wanigaratne and Udamulla (2012) had reported that biosolids were non-plastic. The addition of steel slag reduces the plasticity index from 11.28% to 7.26% for 50:50 ratio. Previous works had reported very high plasticity indices, due to the high liquid limits as mentioned earlier (O'Kelly, 2005; Kayser et al., 2011). Plasticity index values reported by Arulrajah et al. (2011; 2013) was much closer to the value reported in the present work. The reduction in plastic limit and hence, the plasticity values of the blends were due to the fact that steel slag is a non-plastic material and increasing its content in the blends has resulted in the reduction in the plasticity characteristics of the synthetic fill material. However, Akinwumi (2014) states that the replacement of lower valence cations in soil by Ca^{2+} and Mg^{2+} ions in steel slag reduced the size of the diffuse double layer, thereby resulting in aggregation of soil and steel slag particles, resulting in an increase in silt size fractions and reduction in clay size fractions as a reason for decrease in plasticity. Thus, along with the physical changes in the particles' nature due to increasing proportion of steel slag, aggregation due to chemical interaction is a possible reason for reduction in plasticity characteristics. The shrinkage limits of the blends of biosolids with steel slag increased with the increase in the steel slag content. The shrinkage limit of biosolids increased from 10.3% to 15.79% for the 50:50 mix ratio. The increasing content of steel slag reduces the content of biosolids and thus the available quantity of fines that actually are responsible for the volume change on variation of water content. With fewer fines, the shrinkage stops earlier, thereby resulting in a higher shrinkage limit. However, it can be noticed that the variation of shrinkage limit is very marginal beyond 25% steel slag in the blend. This may be an indication that steel slag itself may be susceptible to volume change with variation in water content, though not as much as biosolids. Chen et al. (2007) state that steel slag is liable to volume expansion, due to the hydration of free lime and magnesia present in steel slag.

3.2. Effect of Steel Slag on Compaction

The variation in compaction characteristics of biosolids blended with steel slag is shown in Figures 2a and 2b. Figure 2a shows the compaction curves of biosolids and the three blends. It can be clearly seen that the curves for the blends are above and to the left of the compaction curve for biosolids indicating improvements in maximum dry density and optimum moisture content. Figures 2b shows variations in optimum moisture content (OMC) and maximum dry density (MDD) of biosolids-steel slag blends respectively. With increase in steel slag content, there is a decrease in OMC. However, the reduction in OMC is insignificant beyond 25% steel slag in the blend. This can be indirectly taken as an indication of the observation made by Chen et al. (2007) whence steel slag also uses up moisture content in hydration of free lime and magnesia. The reduction in optimum moisture content due to addition of steel slag was attributed by Akinwumi (2014) to the agglomeration of clay particles, due to the reduction in the diffuse double layer, leading to lower water requirements for reaching optimum. The addition of steel slag results in an increase in MDD, due to the fact that steel slag is heavier than biosolids and the introduction of varying particle sizes for better grading results in better packing during compaction.

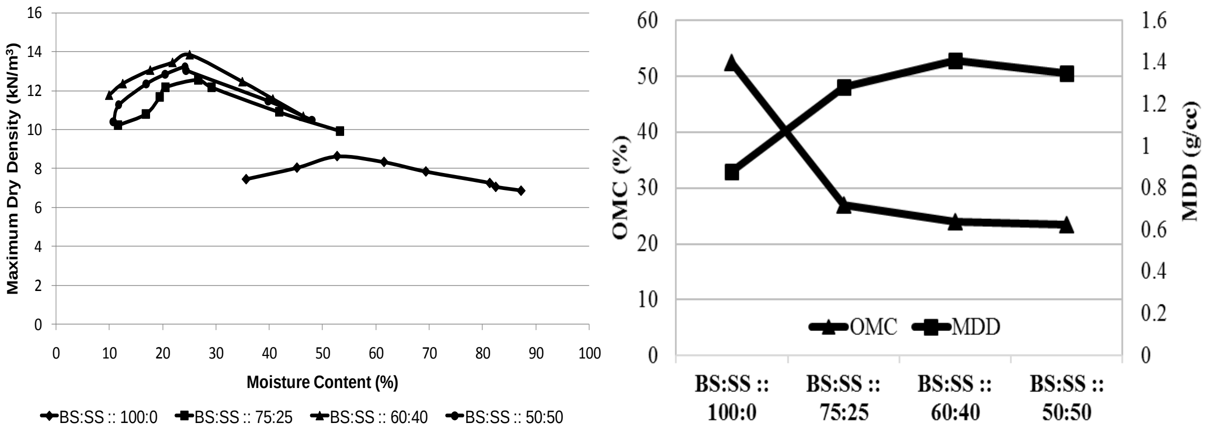

Figure 2 (a) Compaction curves; (b) variation of OMC and MDD of different blends

Akinwumi (2014) stated that the higher specific gravity of steel slag is responsible for increase in maximum dry density. But it can be noticed that, compared to earlier trends, the maximum dry density is achieved with the 60:40 combination rather than the 50:50 combination of biosolids-steel slag. A possible explanation can be that the voids formed by large steel slag particles are filled up with the smaller sized biosolids particles. In the 60:40 blend, there may have been an optimal balance between the voids formed and available biosolids to fill up the voids, whereas in the 50:50 blend this balance may have been disturbed due to more voids with increasing steel slag and lesser biosolids as filler for the voids. However, Disfani et al. (2009) reported a continuous increase in dry density with increasing percentage of fine recycled glass in biosolids.

3.3. Effect of Steel Slag on UCC Strength

Addition of steel slag to biosolids has resulted in increase in the unconfined compressive (UCC) strength of the blend as seen in Figures 3a and 3b. Figure 3a shows the stress-strain curves for the various blends. Similar trends are seen at lower strain levels of less than 20% whereas at higher strain levels, the curves start to separate out with the 75:25 blend producing the maximum strength of close to 33 kPa, which is a 44% gain in strength compared to that of biosolids alone at 23 kPa, as seen in Figure 3b. All blends produced maximum strengths at a strain rate of 50%.

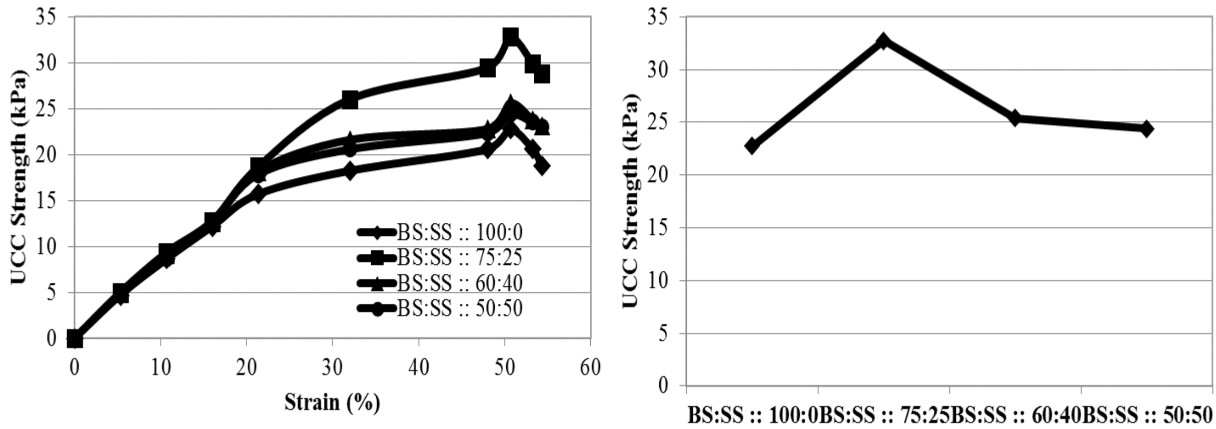

Figure 3 (a) Stress strain curves; (b) variation of strength of different blends

Disfani et al. (2009) had reported an increase in friction angle of biosolids blended with increasing proportion of fine recycled glass up to 50%, beyond which there was no significant increase. Chen et al. (2014) reported that deeply dewatered sewage sludge produced shear strength in the range of 58 to 104 kPa. Though the maximum density was obtained for the 60:40 blend, the UCC strength for the 75:25 blend was higher than the former combination. This may be due to insufficient biosolids in the 60:40 mix matrix to keep the blend together resulting in early failure, compared to the 75:25 mix. Akinwumi (2014) found that increase in steel slag increased the UCC strength of the soil up to 8% steel slag content, beyond which it reduced.

3.4. Effect of Steel Slag on CBR

The effect of steel slag on the Unsoaked California Bearing Ratio (CBR) value of biosolids-steel slag blends is shown in Figures 4a and 4b. It can be clearly observed that the steel slag content in the blend is directly proportional to the CBR value.

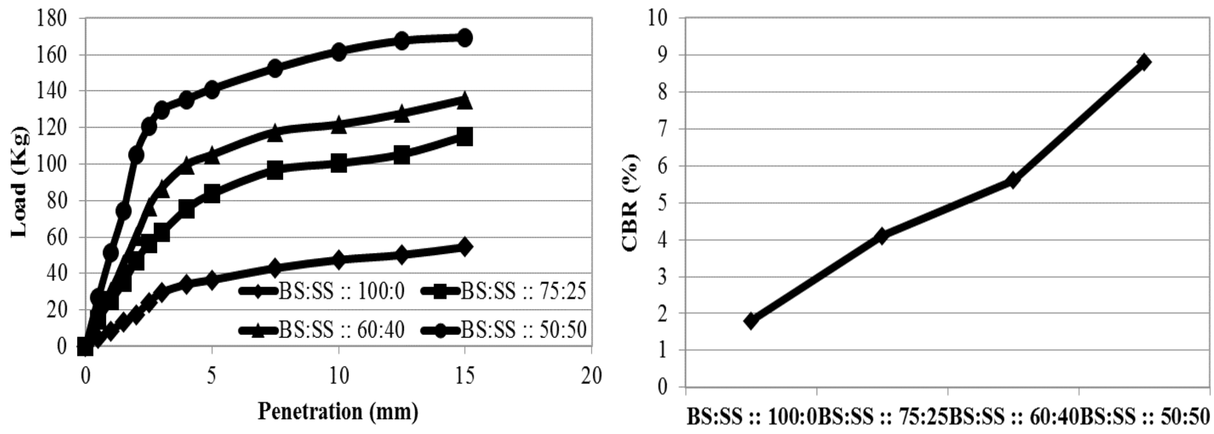

Figure 4 (a) CBR curves; (b) variation of CBR of different blends

The increase in steel slag content has increased the CBR from 1.8% to 8.8% for the 50:50 ratio. The CBR value for biosolids in the present study is slightly higher than the values reported by

Arularajah et al. (2011; 2013) but lesser than the value reported by Wanigaratne & Udamulla (2012). Disfani et al. (2009) reported marginal increase in CBR until 40% addition of fine recycled glass to biosolids beyond which there was a significant rise in CBR value. The increased CBR values may be due to the increase in steel slag which is a stiffer material when compared to the easily compressible biosolids.

4. CONCLUSION

In this investigation, the effect of blending biosolids with steel slag was investigated in order to enhance the performance of biosolids and hence its suitability as a synthetic fill for geotechnical fill applications. Based on the results of the various tests, the following may be concluded: (1) Natural biosolids can be classified as an organic soil of high plasticity which is not suitable for use in geotechnical fills, due to its compressible nature; (2) Blending of biosolids with a frictional material like steel slag improved its index properties especially its plasticity characteristics; (3) The results of the strength and CBR tests indicated that the ratios 75:25 and 50:50 of BS:SS produced the highest strength and CBR values respectively; (4) Based on the comparison of all properties, it is suggested that 25 to 40% steel slag blending will produce optimal results in enhancing the bearing of biosolids; (5) The obtained values of CBR, though an improvement over biosolids, are still low for adoption in the field. It is hence recommended that a combination of other industrial wastes like fly ash, lime kiln dust, cement kiln dust, bottom ash etc. can be adopted along with steel slag for improving performance; (6) However, it should be noted that the compressibility and permeability characteristics of the proportioning have not been studied in this investigation. Hence, compressibility and permeability characteristics of the biosolids-steel slag blends need to be studied in further investigations whose results will give an indication of long term performance of the recommended blends and help identify the best blend ratio, thus, giving the complete performance potential as synthetic fill material for fill applications.

It can thus be concluded that biosolids, which were hitherto considered as a waste material resulting in disposal problems, with more research, are potential materials for use in geotechnical applications by blending with other suitable industrial wastes like steel slag.

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