# Compaction and Sub-grade Characteristics of Clayey Soil Mixed with Foundry Sand and Fly Ash

**Dr. Ravi Kumar Sharma*, Amrendra Kumar****

*(Professor, Department of Civil Engineering, National Institute of Technology, Hamirpur, India)

** (PG student, Department of Civil Engineering, National Institute of Technology, Hamirpur, India)

## Abstract

*This paper describes the results of laboratory investigation conducted to evaluate the impact on sub-grade characteristics of clayey soil blended with foundry sand and fly ash. Foundry sand and fly ash both are waste materials obtained from different industries imposing hazardous effect on environment and human health. Although utilization of foundry sand and fly ash are continuing to grow, but still there is substantial quantity that remains unutilized. The inherent properties of foundry sand and fly ash can be used to obtain an effective sub-grade material with combination of clayey soil and the problems of their disposal can be solved to some extent. The results show that with addition of foundry sand and fly ash to clayey soil, its strength and compaction characteristics are improved.*

**Keywords:** Clayey soil, foundry sand, fly ash, compaction and California bearing ratio.

## 1. Introduction:

Foundry sand is high quality silica sand with uniform physical characteristics. It is a by-product of ferrous and non-ferrous metal casting industries, where sand has been used for centuries as a molding material because of its low thermal conductivity. Foundries successfully recycle and reuse sand many times in the casting process. When the sand can no longer be reused in the foundry, it is removed from the casting process and is termed as waste foundry sand. The production of waste foundry sand is increasing rapidly in India which is causing severe disposal problem. Similarly, fly ash is also a major concern to the remediation experts because fly ash contains trace levels of heavy metals and other toxic substances which pose threat to human health. Due to the above reasons, the utilization of waste foundry sand and fly ash is attracting lot of researcher's attention. In recent years, significant work has been done to use foundry sand and fly ash in construction activities.

Some of the application areas of foundry sand include highway bases and retaining structures (Kirk, 1998; Mast and Fox, 1998; Goodhue et al., 2001), landfill liners (Abichou et al., 1998, 2004), asphalt concrete (Javed and Lovell, 1995), flowable fill (Bhat and Lovell, 1996), and pavement bases (Kleven et al., 2000). Other studies have shown that the thermal or biological remediation of foundry sand provides an opportunity for their land applications (Leidel and Novakowski, 1994; Reddi et al., 1996). Existing research has shown that foundry sand can be effectively used in geotechnical construction due to its comparable properties with sand-bentonite mixtures (Abichou et al., 2004). Bhuvaneshwari (2005) concluded that workability and maximum dry density was achieved at 25% of fly ash. Edil *et al* (2006) indicated the effectiveness of fly ashes for stabilization of fine grained soils. Chauhan et al (2008) observed that optimum moisture content increases and maximum dry density decreases with increased percentage of fly ash mixed with silty sand. Bose (2012) reported that maximum dry density increases up to 20% fly ash mix, and then gradually decreases whereas the optimum moisture content decreased with increase in fly ash and also CBR values of clay-fly ash mixes tested under un-soaked conditions, shows peaks at 20% and 80% ash content. However, limited information exists about the combined use of foundry sand and fly ash in soil stabilization. In this paper, sub-grade characteristics of clayey soil blended with foundry sand and fly ash in different proportions has been studied.

## 2. Experimental Program

### 2.1 Materials:

The soil used in the study was locally available clayey soil and waste foundry sand (FS) obtained from Nahan foundry. According to ASTM classification system (ASTM D2487-11), the soil was classified as clay with medium plasticity (CL) and the properties of clay are given in Table 1. The fly ash (fa) was obtained as residue left after electronic precipitation of the burnt gases. The chemical composition of fly ash is given in Table 2 (ASTM D5239-2004).

**Table 1:** Physical properties of clay, foundry sand and fly ash

| Property | Clay | Foundry Sand | Fly ash |
|---|---|---|---|
| Specific gravity | 2.62 | 2.609 | 1.966 |
| Maximum dry density (MDD), g/cc | 1.929 | 1.573 | 1.164 |
| Optimum moisture content (OMC), (%) | 12.0 | 6.0 | 32.0 |
| Liquid limit (%) | 43.0 | - | 40.0 |
| Plastic limit (%) | 22.6 | - | - |
| Plasticity index (%) | 20.4 | - | - |
| Uniformity coefficient, Cu | - | 1.84 | - |
| Coefficient of curvature, Cc | - | 0.97 | - |
| Soaked CBR (%) | 2.44 | 9.77 | 1.94 |

**Table 2:** Chemical composition of fly ash

| Chemical Composition | Proportion (%) |
|---|---|
| Silica ($Sio_2$) | 55.69 |
| Alumina ($Al_2o_3$) | 26.33 |
| Calcium oxide (Cao) | 3.43 |
| Iron oxide ($Fe_2O_3$) | 6.90 |
| Potassium Oxide ($K_2O$) | 0.98 |
| Sulphur ($SO_3$) | 0.45 |
| Magnesium Oxide (Mgo) | 0.62 |
| Loss on ignition | 5.60 |

### 2.2 Method of Testing

The laboratory tests were conducted in accordance with ASTM standards. The specific gravity tests, consistency limit tests and the standard proctor tests were conducted in accordance with ASTM D854-10, ASTM D4318-10 and ASTM D698-07e1 respectively. The physical properties of clay, foundry sand and fly ash are presented in Table 1. The hydrometer analysis tests were conducted as per ASTM D422-63. The particle size distribution of clay, foundry sand and fly ash tested as per ASTM D6913-04 (2009) are given in Figure 1. The sizes of the compaction molds used were of 101 mm diameter and 125 mm height. Compaction tests were conducted on clay with varying percentages of foundry sand from 10% to 50% and optimum mixes were obtained. After obtaining optimum mix proportion varying percentages of fly ash is added with clay-foundry sand mix from 10% to 40% in increments of 10%. The California bearing ratio tests were performed in laboratory in accordance with ASTM D1883-05. The sizes of samples were of 150 mm diameter and 125 mm height. Soaked CBR tests were conducted in standard mold for samples compacted statically at maximum dry MDD and OMC. Surcharge weight of 50N was used during the testing. A metal penetration plunger of diameter 50 mm and 100 mm long was used to penetrate the samples at the rate of 1.25 mm/minute using computerized CBR testing machine.

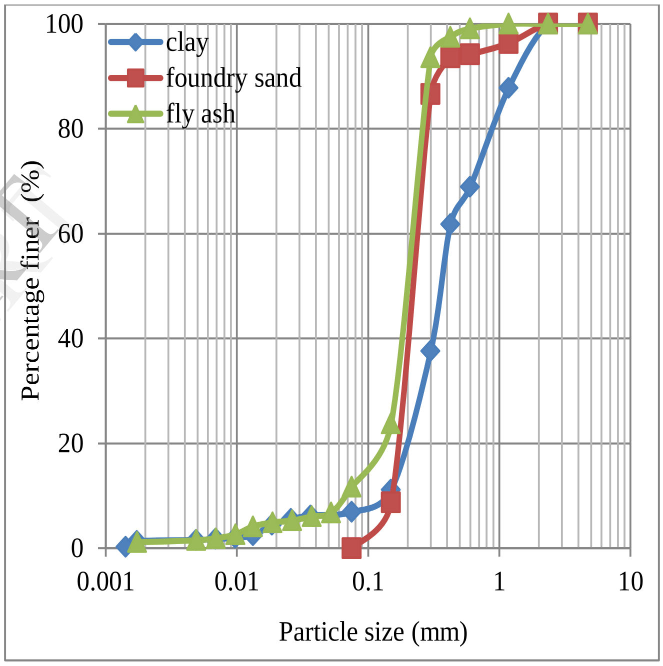

**Figure 1:** Particle size distribution of clay, foundry sand, fly ash

## 3. Results and Discussions

### 3.1. Compaction Tests:

The water content-dry density curves of clayey soil mixed with foundry sand content varying from 10% to 50% are shown in figure 2. It is observed that maximum dry density (MDD) of the clay-foundry sand composite increases with the increase in foundry sand content up to 40% after which it is reduced. This occurs due to the reason that the void spaces between the sand particles are occupied by the clay particles up to a certain percentage thereafter the extra sand content segregates the particles which tends to reduce the density.

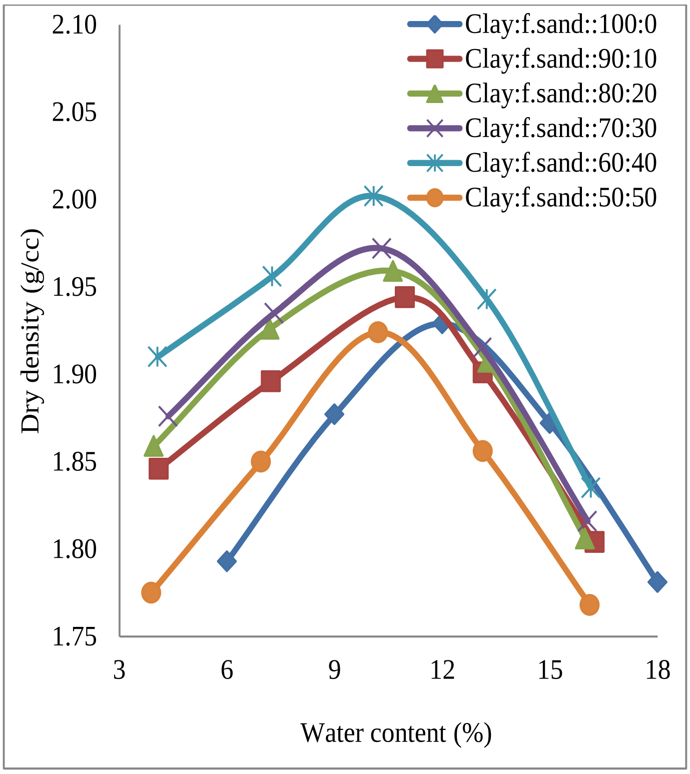

**Figure 2:** Compaction characteristics of clay-foundry sand mixes

The variation of maximum dry density of various clay-foundry sand mixes is shown in figure 3. It is observed that maximum dry density of clay-foundry sand composite increases with increase in sand content up to 40% after which it is reduced. The voids between the foundry sand particles are occupied by the clay particles when the sand content is less but larger sand content segregates the particles and the maximum dry density decreases.

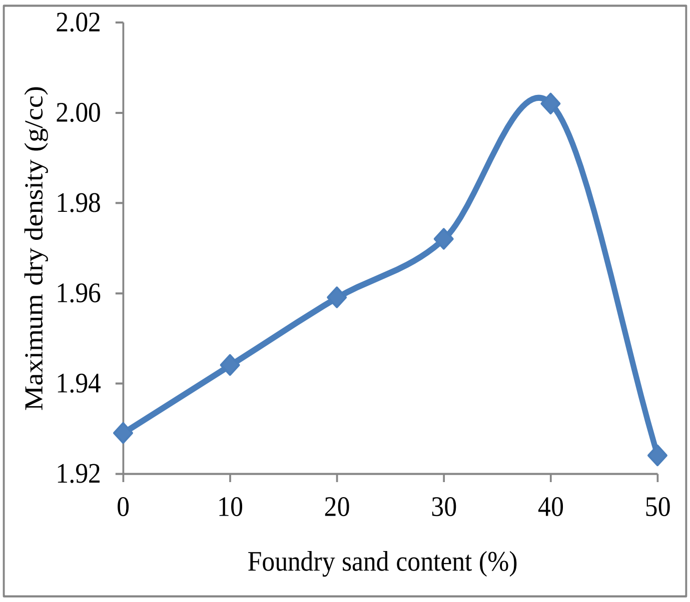

**Figure 3:** Variation of maximum dry density with foundry sand content

The variation of optimum moisture content (OMC) with addition of foundry sand to clay is shown in figure 4. The OMC decrease up to the highest value of maximum dry density later variation in OMC is very little.

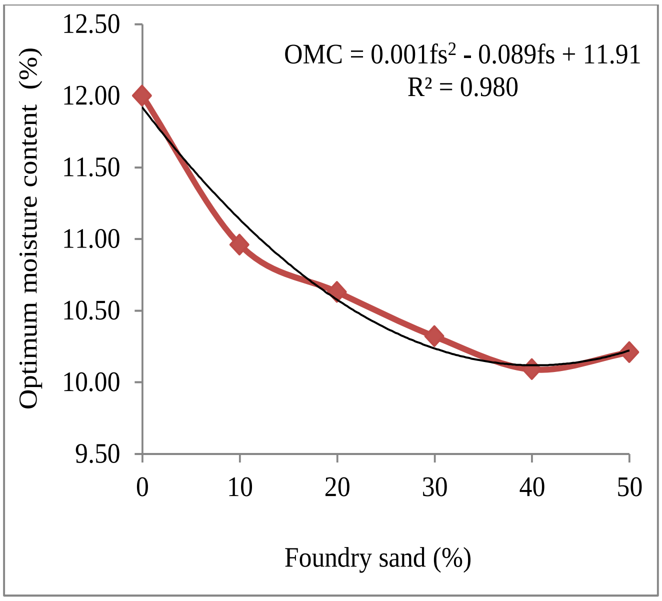

**Figure 4:** Variation of optimum moisture content with different clay-foundry sand mixes

On polynomial regression model, the relationships between the percentage of foundry sand and optimum moisture content of the clay; in which optimum moisture content is represented by 'OMC' and percentage of foundry sand is represented by 'fs'; is given by:

$$OMC = 0.001fs^2 - 0.089fs + 11.91$$
$$R^2 = 0.980$$

The water content-dry density curves of the clay-foundry sand composite with fly ash content varying from 10% to 40% is shown in figure 5. The maximum dry density achieved after the addition of fly ash is lesser compared with clay-foundry sand mix. This is due to the reason that the clay particles can fill most of the voids in the foundry sand when mixed in the ratio of 60:40. Further, it is observed that as the fly ash content increases, the maximum dry density decreases but the optimum moisture content increases.

Figure 6 shows the variation of maximum dry density with addition of fly ash content. The value of maximum dry density of clay-foundry sand mix decreases due to addition of fly ash which is a light weight material as compared to clay and foundry sand. This is mainly attributed to flocculated structures formed by addition of fly ash having low specific gravity.

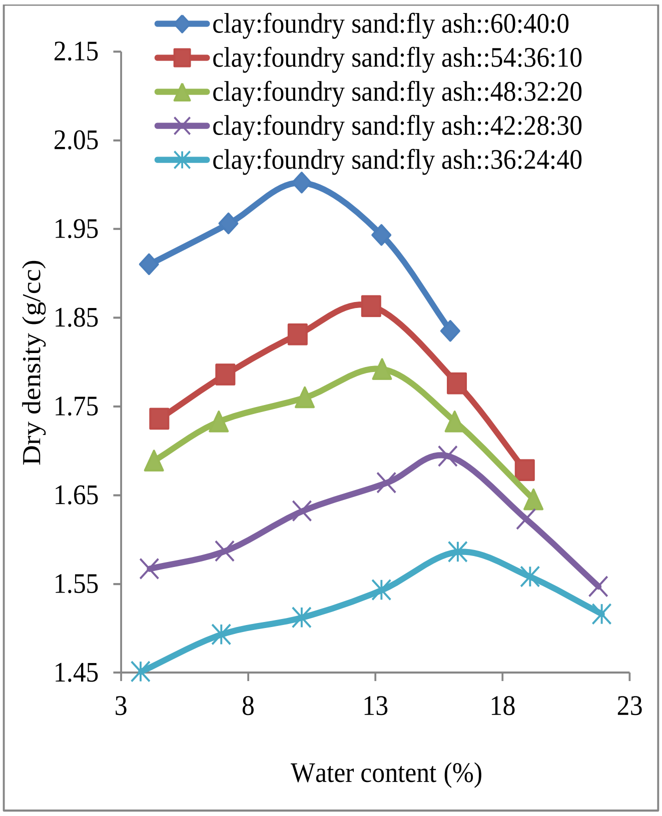

**Figure 5:** Compaction characteristics of clay-foundry sand-fly ash mix

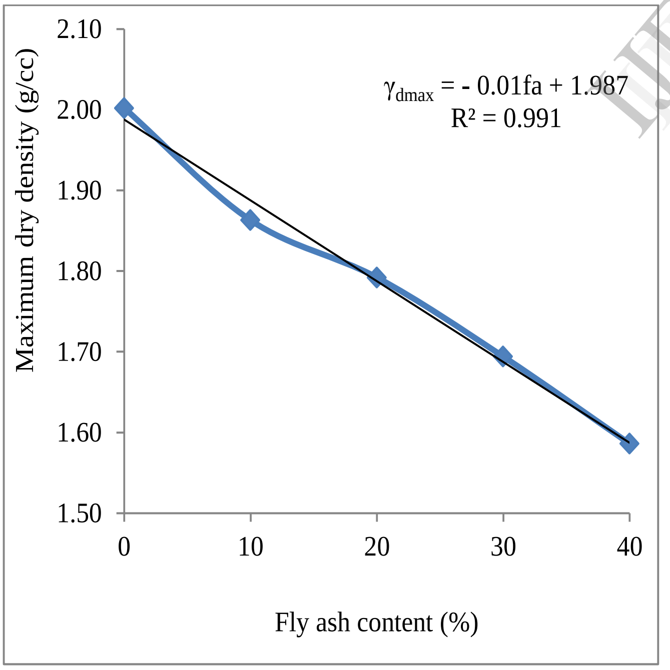

**Figure 6:** Variation of maximum dry density of clay-foundry sand with addition of fly ash

On linear regression model, the relationships between the percentage of fly ash and maximum dry density of the clay-foundry sand mixture (60:40); in which maximum dry density is represented by '$\gamma_{dmax}$' and percentage of fly ash is represented by 'fa'; is given by:

$$\gamma_{dmax} = -0.01fa + 1.9876$$
$$R^2 = 0.9913$$

Figure 7 shows the variation of optimum moisture content with addition of fly ash to the clay-foundry sand mix. The value of OMC decreased with the addition of fly ash to the mix which is inversely proportional to the trend of maximum dry density. On linear regression model, the relationships between the percentage of fly ash and optimum moisture content of the clay-foundry sand (60:40); in which optimum moisture content is represented by 'OMC' and percentage of fly ash is represented by 'fa'; is given by:

$$OMC = 0.152fa + 10.61$$
$$R^2 = 0.936$$

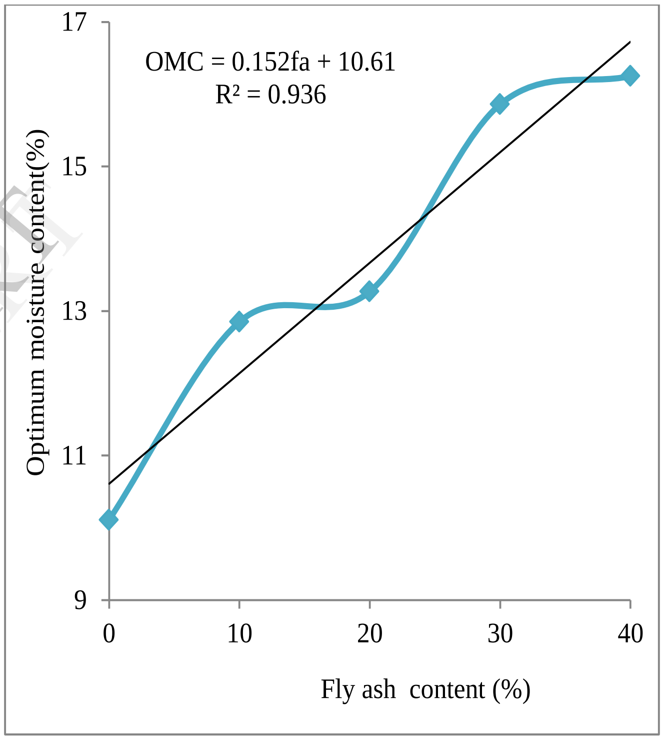

**Figure 7:** Variation of optimum moisture content of clay-foundry sand composite with addition of fly ash

## 4.2. California Bearing Ratio Tests

The results of California bearing ratio (CBR) tests on clayey soil treated with foundry sand and fly ash are shown in figure 8. It is observed that soaked CBR value of clayey soil increased with addition of foundry sand and fly ash. The value of CBR increases from 2.44% for un-stabilized soil to 5.10% for stabilized soil. The improvement in CBR value may be attributed to better compaction and packing of the mix particles with addition of foundry sand and fly ash.

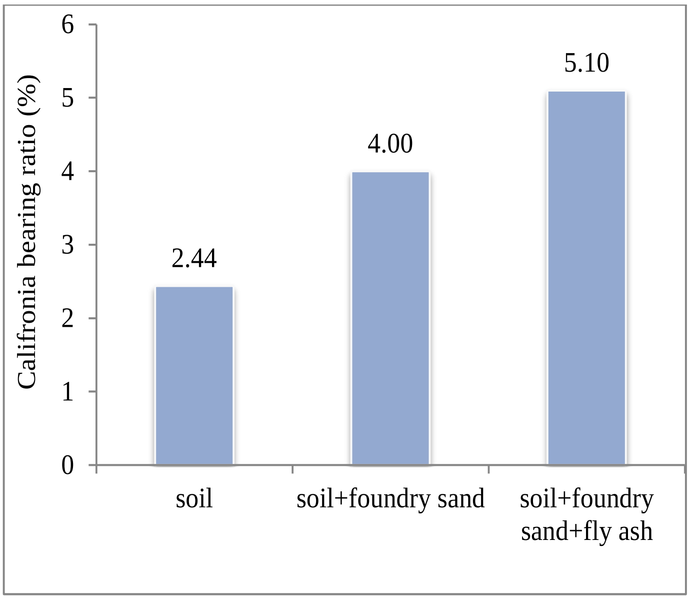

**Figure 8:** Variation of soaked CBR value with optimum mix

The California bearing ratio provides a basis of designing the sub-grades of flexible pavements. Usually, a value of CBR more than 5.0 is considered to be satisfactory for the design of flexible pavements with traffic intensity of 1 to 10 million standard axles (msa). Thus, the clayey soil blended with foundry sand and fly ash can be effectively used in the construction of sub-grades of roads with low traffic volume.

## 5. Conclusions

The following conclusions can be drawn from the study conducted on clayey soil-foundry sand-fly ash mix:

1. The highest value of maximum dry density is achieved for clay-foundry sand mix of 60:40 followed by other proportions (Figure 3). This occurs due to the reason that the voids between the foundry sand particles are occupied by the clay particles when the sand content is less but larger sand content segregates the particles and the maximum dry density decreases.
2. The optimum moisture content of clayey soil-foundry sand mix decreased with the addition of foundry sand (up to 40% content) whereas it increased afterwards (Figure 4). This occurs due to lower quantity of water required to lubricate the foundry sand particles which are coarser compared with clay particles.
3. The maximum dry density of clay-foundry sand (60:40) mix decreased with addition of fly ash which is a light weight material as compared to clay and foundry sand (Figure 6). This is mainly attributed to flocculated structure formed by addition of fly ash having lesser specific gravity. However, the clay: foundry sand: fly ash (54:36:10) mix was considered for conducting California bearing ratio tests.
4. The optimum moisture content of clayey soil-foundry sand-fly ash mix increased with the addition of fly ash (Figure 7). This occurs due to the fact that the optimum moisture content of fly ash is higher (since the fly ash particles are much finer and rounded in shape) as compared to that of clayey soil and foundry sand (Table 1).
5. The California bearing ratio value of clayey soil improved significantly i.e. from 2.44% to 5.10% with addition of foundry sand and fly ash (Figure 8).
6. Thus, clayey soil stabilized with foundry sand and fly ash can be used as a sub-grade material for construction of flexible pavements in rural roads with low traffic volume.

## References

[1] Abichou, T., Benson, C.H., Edil, T.B., & Freber, B.W., “Using Waste Foundry Sand for Hydraulic Barriers,” In: Vipulanandan, C., Elton, D. (Eds.), *Recycled Materials in Geotechnical Applications, Geotechnical Special Publication* 79. ASCE, Boston, MA, pp. 86–99, 1998.

[2] Abichou, T., Benson, C.H., Edil, T.B., & Tawfiq, K., “Hydraulic Conductivity of Foundry Sands and Their use as Hydraulic Barriers,” In: Aydilek, A.H. & Wartman, J. (Eds.), *Recycled Materials in Geotechnics, Geotechnical Special Publication* 127. ASCE, Baltimore, Maryland, 2004.

[3] ASTM D422-63, “Standard test methods for hydro meter analysis of soils,” *American Society for Testing of Materials*, Pennsylvania, Pa, USA.

[4] ASTM D698-07e1, “Standard test methods for laboratory compaction characteristics of soil using standard effort,” *American Society for Testing of Materials*, Pennsylvania, Pa, USA.

[5] ASTM D854-10, “Standard test methods for specific gravity of soil,” *American Society for Testing of Materials*, Pennsylvania, Pa, USA.

[6] ASTM D1883-05, “Standard test methods for California bearing ratio test for soils,” *American Society for Testing of Materials*, Pennsylvania, Pa, USA.

[7] ASTM D2487-11, “Standard practice for classification of soils for engineering purposes (unified soil classification system),” *American Society for Testing of Materials*, Pennsylvania, Pa, USA.

[8] ASTM D4318-10, “Standard test methods for liquid limit, plastic limit, and plasticity index of soils,” *American Society for Testing of Materials*, Pennsylvania, Pa, USA.

[9] ASTM D5239-2004, “Standard practice for characterizing fly ash for use in soil stabilization,” *American Society for Testing of Materials*, West Conshohocken, PA, USA.

[10] ASTM D6913-04, “standard test methods for particle size distribution of soils,” *American Society for Testing of Materials*, Pennsylvania, Pa, USA.

[11] Bhat, S.T. & Lovell, C.W. (1996). Use of Coal Combustion Residues and Waste Foundry Sands in Flowable Fill, *Purdue University-Joint Highway Research Project Report*, Federal Highway Administration, Washington, DC, 240 p.

[12] Bhuvaneshwari, S., Robinson, R.G. and Gandhi, S.R., "Stabilization of expansive soils using fly ash,"*Fly Ash India,* 2005, Fly Ash Utilization Programme (FAUP), TIFAC, DST, New Delhi.

[13] Bose, B., "Geo engineering properties of expansive soil stabilized with fly ash," *Electronic Journal of Geotechnical Engineering*, Vol. 17, Bund. J, 2012

[14] Chauhan, M.S., Mittal, S. and Mohanty, B., "Performance evaluation of silty sand sub-grade reinforced with fly ash and fiber," *Geotextiles and Geomembranes,* Vol. 26, Issue 5, pp. 429-435, 2008.

[15] Edil, T.B., Acosta, H.A., and Benson,C.H., "Stabilizing soft fine grained soils with fly ash," *Journal of Materials in Civil Engineering,* ASCE 18(2), 283-294, 2006.

[16] Goodhue, M., Edil, T.B., & Benson, C.H., "Interaction of Foundry Sand with Geo-synthetics," *Journal of Geotechnical and Geo-environmental Engineering,* 127 (4), pp. 353–362, 2001.

[17] Javed, S. & Lovell, C.W., "Uses of waste foundry sand in Civil Engineering", *Transportation Research Board Record*, 1486, pp. 109–113, 1995.

[18] Kirk, P.B., "Field demonstration of highway embankment constructed using waste foundry sand," *Ph.D. Dissertation, Purdue University, West Lafayette, IN*, 202 p, 1998.

[19] Kleven, J.R., Edil, T.B. & Benson, C. H., "Evaluation of excess foundry system sands for use as sub-base material," *Proceedings of the 79th Annual Meeting, Transportation Research Board*, Washington, DC, 2000.

[20] Leidel, D.S. & Novakowski M., "Beneficial Sand Reuse: Making it Work. Modern Casting", 84 (8), 28–31, 1994.

[21] Mast, D.G. & Fox, P.J., "Geotechnical performance of highway embankment constructed using waste foundry sand", In: Vipulanandan, C. & Elton, D. (Eds.), *Recycled Materials in Geotechnical Applications, Geotechnical Special Publication* 79. ASCE, Boston, MA, pp. 66–85, 1998.

[22] Reddi, L.N., Rieck, G.P., Schwab, A.P., Chou, S.T. & Fan, L.T., "Stabilization of Phenolics in Foundry Waste using Cementitious Materials," *Journal of Hazardous Materials* 4 (2–3), pp. 89–106, 1996.