

Effect of Waste Sludge on Compaction Behaviour of Fly Ash

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Abstract— Standard Proctor compaction tests were carried out keeping (i) 30%-50% waste sludge and 70%-50% fly ash (ii) use of fresh/remolded samples; and (iii) preconditioning period as variable parameters. The value of maximum dry density (MDD) of mix 55%FA+45%S was observed as 13 kN/m³ which is about 40% more than MDD value (9.30 kN/m³) of fly ash under fresh condition. However, under remolded condition the mix 60%FA+40%S gives optimum value of MDD (13.40 kN/m³) which is 31% more than the MDD value (10.20 kN/m³) of fly ash under similar test condition. For the estimation of MDD of fly ash and fly ash-waste sludge, a linear empirical model has been chosen in terms of optimum moisture content (OMC) and specific gravity (G). The proposed method has been validated for Harduaganj fly ash and fly ash-waste sludge mixes.

Keywords— Standard Proctor Compaction Test, Waste Sludge; Preconditioning Period, Maximum Dry Density, Optimum Moisture Content, Empirical Model.

I. INTRODUCTION

India is the World's largest producer of fly ash. Its production may soon reach to the tune of 250 MT per year. Fly ash is hazardous to health, and pollutes air and water and occupies several thousand hectares of land for its disposal. The level of utilization of fly ash in India is very low. If the utilization is not increased substantially, the menace of fly ash will grow and may become alarming in many parts of the country. One the other hand one of the major hazardous waste generating industries is the electroplating industry due to the presence of high concentration of heavy metals such as Ni, Cr, Pb, Cu, Cd and Zn etc., [1]. As the restrictions on landfilling become stronger and wastes were banned from land disposal, Stabilization (S/S) of these wastes could potentially play an important role in making them acceptable for land disposal. Lower permeability and lower contaminant leaching rates can make banned wastes acceptable for land disposal after S/S [2]. This has attracted the attention of many researchers to stabilize the waste sludge containing heavy metals using fly ash and cement ([3]-[8]). In order to open up these possibilities, understanding the compaction behaviour of fly ash alone and with electroplating waste sludge is prerequisite and one of the pivotal factors in the building of roads and airport, structure's foundation and embankments is compaction property of material.

Studies on compaction properties of soils and fly ash reported in the literature ([9]-[18]). However, the compaction

studies of fly ash and electroplating waste are not commonly available in literature.

With the aim to utilize the fly ash and electroplating waste sludge for highway and geotechnical applications, the study of compaction behaviour of fly ash and fly ash-waste sludge blend becomes imperative. The waste sludge was added to fly ash 5% to 60% with an increment of 5% by weight of fly ash. The studies were carried out for all combinations of fly ash-waste sludge blend. However, on the basis of compressive strength and leaching tests of mix [19] the effective percentages of waste sludge were found between 30%–45% by weight of fly ash. Therefore, for practical consideration the results of 70%–55% fly ash and 30%–45% electroplating waste sludge have been considered in this study.

II. TEST MATERIALS

In this study, the materials used are Fly ash; Electroplating Waste Sludge; Lime and Cement.

A. Fly ash

Fly ash was procured from Harduaganj thermal power plant located at 16 km from Aligarh City, Uttar Pradesh, India. This power plant consist of 440 MW pulverised coal units, producing 25 trucks of fly ash and bottom ash per day which is about 1500 tonnes fly ash and 500 tonnes of bottom ash. For the present investigation, dry fly ash from hoppers is collected in polythene bags.

1) Physical Properties

Colour= Grey, Percent finer= 88%, Size of the particle= 0.002-0.30mm, Maximum dry density (MDD)= 9.30 kN/m³, OMC= 27.5%, Specific gravity = 2.02, Surface area= 3060 cm²/g, Unburnt carbon= 11.80% and Classification = ML as per IS: 1498-1987.

2) Chemical Composition

The chemical composition of fly ash are SiO₂= 54.0, Al₂O₃= 24.0, Fe₂O₃= 12.0, CaO = 2.0, MgO= 1.0, SO₃= 0.3 and Loss on Ignition (Percent by Weight) = 1.5 %.

B) Electroplating Waste Sludge

The electroplating waste sludge was collected in the form of filter cake, comprises of 70% solid waste and 30% waste water (Fig. 1). The solid waste includes chemicals, heavy metals and metallic dust. Heavy metal analysis was carried out using GBC-902 atomic absorption spectrophotometer (AAS). The heavy metals concentration in the electroplating waste sludge was found as Nickel= 610, Chromium= 630, Zinc= 800, Cadmium= 025, Copper= 300 and Lead = 005 ppm.



Fig. 1 Mixed Electroplating Waste Sludge before Treatment and Precipitation (Collected from Source)

C) Lime

The finely powered white coloured lime was used as precipitator having the chemical composition such Assay= 95, Chloride = 0.01, Sulphate=0.2, Aluminium, iron and insoluble matters=1.0, Arsenic=0.0004 and Lead =0.001%.

III. METHODOLOGY

Proctor tests were carried out using the equipment and procedure as specified in IS: 2720 (Part 7–1987) for standard Proctor test (equivalent to ASTM D 698–2000a). Keeping the Fresh/Remoulded samples for each test. The test matrix for this study is shown in Table–1. Fresh sample means, for each moisture content, fresh sample is used while remoulded sample means the same sample is used repeatedly for compaction with different moisture contents. Three replicate tests were carried out for each condition.

Table–1 DETAILS OF TEST CONDITIONS

S. No.	Mix	Standard Proctor Tests
		Fresh/Remoulded
1.	Fly ash	Both
2.	70%FA+30%S	Both
3.	65%FA+35%S	Both
4.	60%FA+40%S	Both
5.	55%FA+45%S	Both
6.	50%FA+50%S	Both

IV RESULT AND DISCUSSIONS

1) Effect Of Using Fresh And Remoulded Samples

While carrying out compaction test, two practices are generally followed; (i) fresh samples are used for compaction at every moisture content (ii) the same sample is repeatedly used (remoulded) for compaction at different moisture contents. Some typical results of standard Proctor compaction tests obtained for fly ash and fly ash–waste sludge blend adopting the above two practices are presented in Figs. (2 to 9). The MDD and OMC values obtained as an average of three replicate tests are presented in Table–2.

Table–2 EFFECT OF FRESH/REMOULDED SAMPLES ON MDD AND OMC

Mix	Fresh Sample		Remoulded Sample	
	MDD (kN/m ³)	OMC (%)	MDD (kN/m ³)	OMC (%)
Fly ash (FA)	09.30	27.5	10.20	26.50
70%FA+30%S	11.50	27.0	11.90	26.00
65%FA+35%S	12.06	26.5	13.20	24.80
60%FA+40%S	12.40	23.0	13.40	22.00
55%FA+45%S	13.00	24.5	13.10	24.00
50%FA+50%S	12.65	25.0	13.00	23.50

The results show that the use of remoulded sample increases the value of MDD and decreases the value of OMC for fly ash and fly ash–waste sludge blend. This may be attributed to crushing of ash grains due to repeated compaction of the sample as well as enhanced lubrication mechanism due to uniform distribution of moisture in the fly ash–waste sludge blend. It may also be observed that the increase in the MDD of remoulded samples of fly ash–waste sludge blend is more significant than fly ash. The percent increase in MDD values of remoulded samples with respect to fresh samples are 9.67% for fly ash, 3.47% for 70%FA+30%S and 8%, 9.4%, 1.0% & 2.76% for 65%FA+35%S, 60%FA+40%S, 55%FA+45%S and 50%FA+50%S mixes respectively. This indicates that the delay in mixing and laying of the mix at site may not cause decrease in the MDD values. However, the use of fresh samples would simulate the field condition more closely the procedure of using fresh samples may be adopted for carrying out compaction tests on fly ash, fly ash–waste sludge blend.

2) Influence Of Preconditioning Period

Compaction tests on fly ash and fly ash–waste sludge samples with preconditioning period as 0 hr, 1 hr, 16 hr and 24 hr, as shown in Figs. 2 to 10, show some typical results. The MDD and OMC values obtained with different preconditioning period are also presented in Table–2. These results are the average of three replicate tests. The results

show that MDD value is affected due to varying preconditioning period.

Sivapulliah *et al.* [20] have reported that MDD value significantly affected in case of Neyveli fly ash (CaO–9.0%) and only marginally affected in case of Vijayawada pond ash (CaO–3.03%) due the effect of preconditioning period. When compared with the MDD values corresponding to 0 hr preconditioning period, the Neyveli fly ash exhibited a variation of the order of 15%, the Vijayawada pond ash 0.3%, Dadri fly ash 5% due to longer preconditioning period and Harduaganj fly ash 5.3% due to longer preconditioning period. The values of MDD of fly ash obtained in the present study show similar trend upto 0 hr as reported by [21] for both standard and modified tests. However, for fly ash–waste sludge mix the MDD values are increasing upto preconditioning period of 16 hr, afterwards it decreases at preconditioning period of 24 hr. The increase in MDD values for blend upto 16 hr might be due to uniform distribution of moisture in the mix leading to the enhanced lubrication mechanism results in increase in MDD values. As shown in Figs. 10 and 11, the percentage increase in the value of MDD of fly ash–waste sludge blend for 16 hr of preconditioning period with respect to 0 hr for standard test are 8.6% for 70%FA+30%S and 24.3%, 12.9%, 16.2% and 4.3% for 65%FA+35%S, 60%FA+40%S, 55%FA+45%S and 50%FA+50%S respectively. The most significant mix is found 55%FA+45%S whereas, the MDD values of mix 50%FA+50%S have not been increased significantly with increase in preconditioning period. The finding indicates that due to carbonation reaction, the mix 50%FA+50%S becomes porous results in decrease in MDD values.

3) Influence Of Waste Sludge

The results of standard Proctor compaction tests on fly ash–waste sludge mix are shown in Figs. 2 to 11 and Table–2. It is envisaged that the values of MDD are significantly increasing with addition of waste sludge to the fly ash. It may also be observed that the most significant waste sludge percentage is between 35% to 45% by weight of fly ash. However, on increasing the waste sludge beyond 45%, the maximum dry density of fly ash–waste sludge blend decreases and optimum moisture content increases. This may be attributed to the presence of excess amount lime in the mix, which reacts quickly with the fly ash and brings changes in base exchange aggregation and flocculation, resulting in increased void ratio of the mix leading to a decreased density of the mix. On the other hand it has also been observed that the mix containing high percentage of fly ash may possess low value of MDD and high value of OMC. This might be due to the dominance of fly ash which is having a relatively low specific gravity results in reduced MDD value. The increase in optimum moisture content can be attributed towards the increasing amount of fines which require more water content due to increased surface areas. The values of MDD are increasing whereas the OMC values are decreasing with increase in preconditioning period from 0-16 hours for all the

combinations of fly ash–waste sludge blend. On the other hand the value of MDD of fly ash decreases after 1 hour of preconditioning period. Therefore, this finding reveals that the delay caused due to mixing and laying of the mix at site at least upto 16 hours may not cause decrease in the density of the mix blend.

4) Empirical Models For MDD And OMC Of Fly Ash And Mix Blend

The strength and deformation characteristics of fly ash are improved by compaction. Apparently, both MDD and OMC are the most important parameters for field compaction control. From the previous literature and also from the present investigations, it is revealed that there is large variation of MDD and OMC for fly ash and fly ash–waste sludge samples. For the above mentioned reasons, the checking of MDD and OMC in the field is also laborious. For the estimation of MDD of fly ash and fly ash–waste sludge, following linear empirical model has been chosen in terms of OMC and specific gravity (G) suggested by Bera *et al.* [16] for Dadri pond ash.

First of all the validity of the present model has been examined by determining the MDD and OMC values of the Harduaganj fly ash, then the same may be extended for predicting the values for the combinations of fly ash–waste sludge mix blend.

$$\text{MDD} = 17.4451(\text{G}) - 0.1386(\text{OMC}) - 22.3595$$

The estimated value of MDD from the above Eq. in case of Harduaganj fly ash, with $G=2.02$ and $\text{OMC}=27.5\%$, is 9.06 kN/m^3 , which is close to the experimental value (9.30 kN/m^3).

The above model has been used to predict the MDD values of the mixes containing 70%FA+30%S, 65%FA+35%S, 60%FA+40%S, 55%FA+45%S and 50%FA+50%S. The computed values of MDD for these mixes are 11.40 kN/m^3 , 11.99 kN/m^3 , 13.00 kN/m^3 , 13.67 kN/m^3 and 13.77 kN/m^3 respectively, which are appreciably close to the observed values (11.5 kN/m^3 , 12.06 kN/m^3 , 12.4 kN/m^3 , 13.0 kN/m^3 and 12.65 kN/m^3) for G values of 2.15, 2.17, 2.20, 2.26 & 2.27 and OMC values of 27%, 26.5%, 23%, 24.5% and 25% respectively. The observed and computed MDD values of these combinations of mixes are shown in Fig. 12. It may be observed that almost 100% data are in the range of $\pm 10\%$ band. Therefore, it may be concluded that the Eq. suggested by Bera *et al.* [16] can be used for determining MDD values of Harduaganj fly ash within the accuracy of $\pm 2.5\%$.

MDD values for other combinations of fly ash–waste sludge mixes can also be computed using this Eq. in the range of accuracy $\pm 10\%$ as well. This Eq. is also useful for field engineers to check the value of reported MDD of fly ash for the given values of OMC and G.

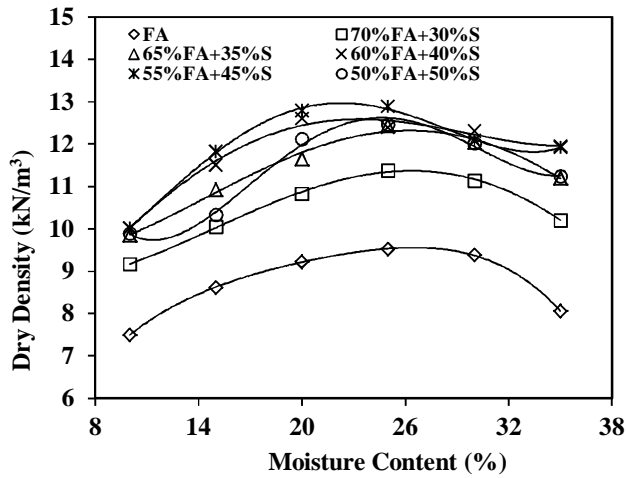


Fig. 2 Effect of Waste Sludge on Compaction Properties of Fresh Fly ash (Standard Proctor Test-Preconditioning Period= 0 hr)

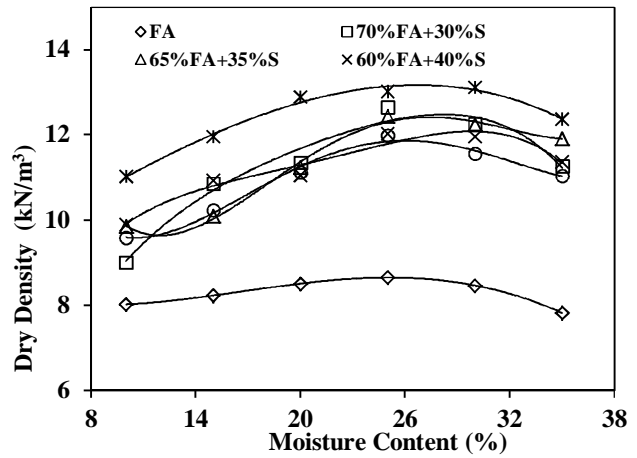


Fig. 5 Effect of Waste Sludge on Compaction Properties of Fresh Fly ash (Standard Proctor Test-Preconditioning Period = 24 hr)

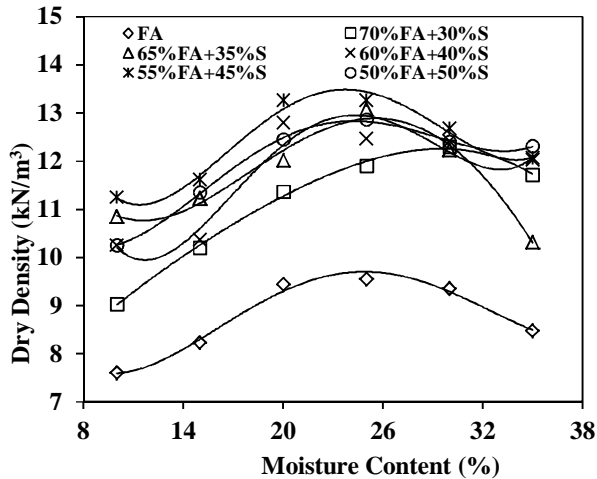


Fig. 3 Effect of Waste Sludge on Compaction Properties of Fresh Fly ash (Standard Proctor Test-Preconditioning Period= 1 hr)

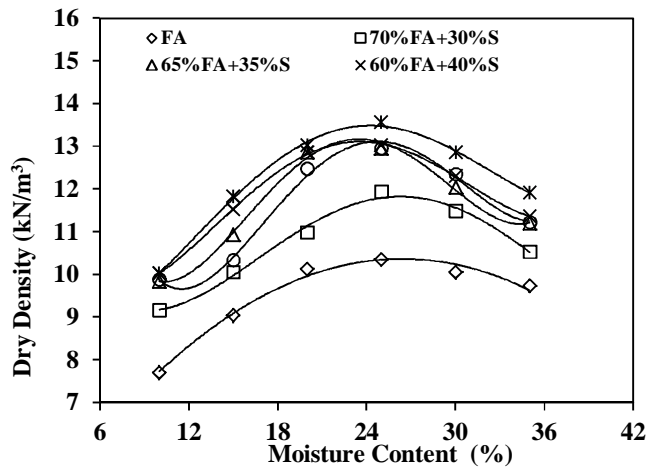


Fig. 6 Effect of Waste Sludge on Compaction Properties of Remolded Fly ash (Standard Proctor Test-Preconditioning Period = 0 hr)

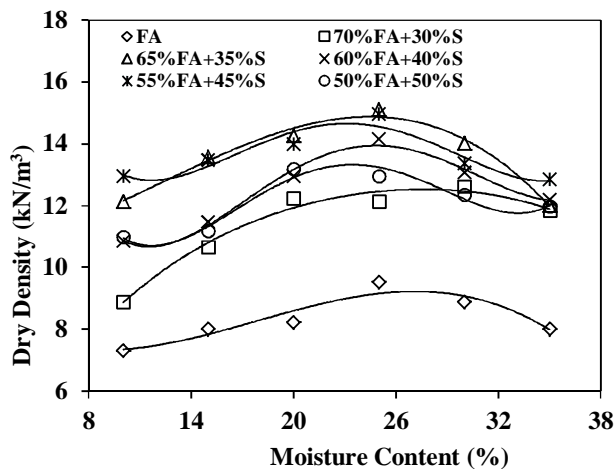


Fig. 4 Effect of Waste Sludge on Compaction Properties of Fresh Fly ash (Standard Proctor Test-Preconditioning Period = 16 hr)

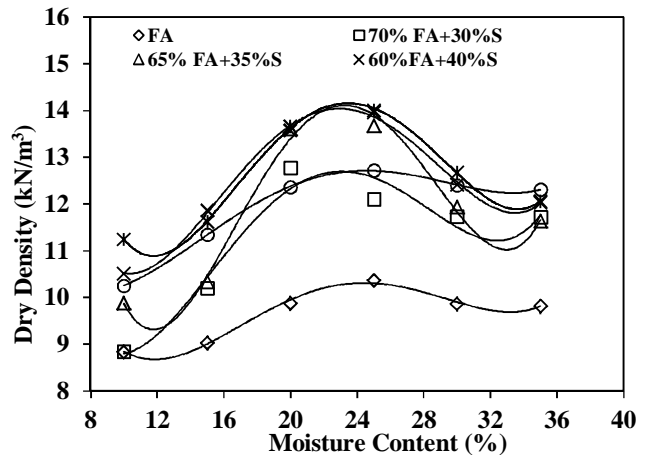


Fig. 7 Effect of Waste Sludge on Compaction Properties of Remolded Fly ash (Standard Proctor Test-Preconditioning Period = 1 hr)

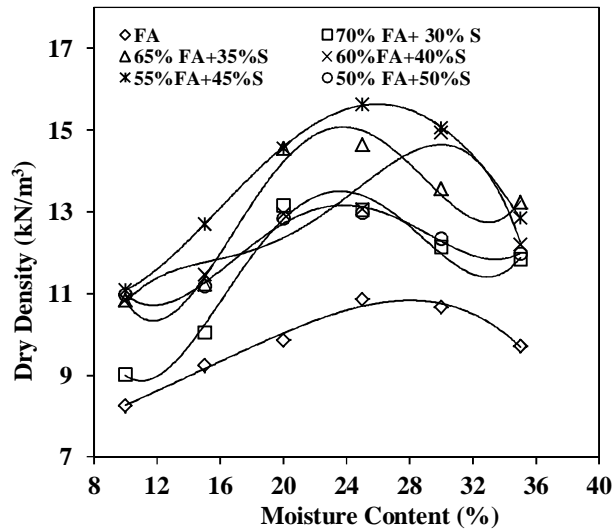


Fig. 8 Effect of Waste Sludge on Compaction Properties of Remolded Fly ash (Standard Proctor Test–reconditioning Period = 16 hr)

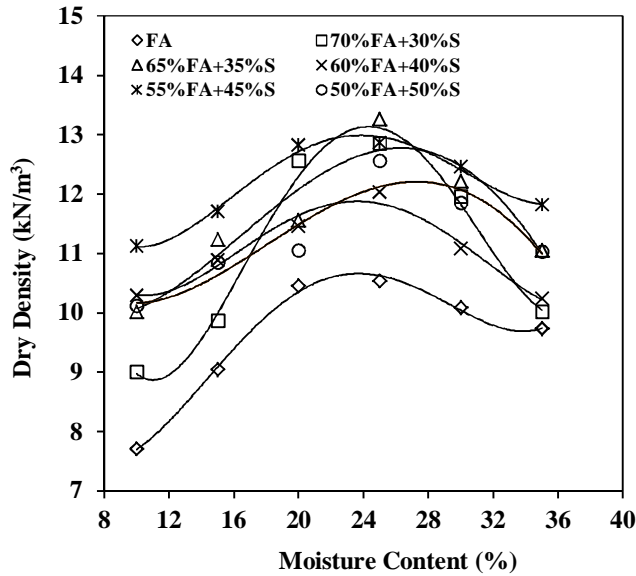


Fig. 9 Effect of Waste Sludge on Compaction Properties of Remolded Fly ash (Standard Proctor Test–Preconditioning Period = 24 hr)

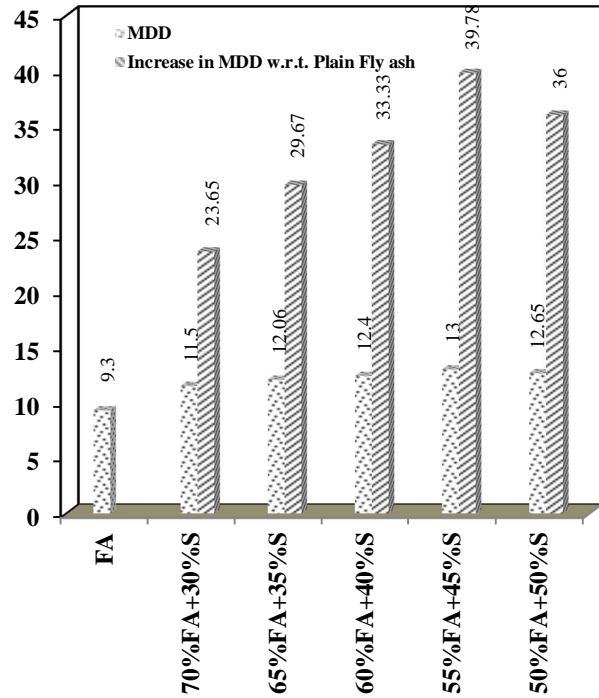


Fig. 10 Effect of Waste Sludge on MDD of Fly ash for Fresh Sample (Standard Proctor Test–Preconditioning Period = 0 hr)

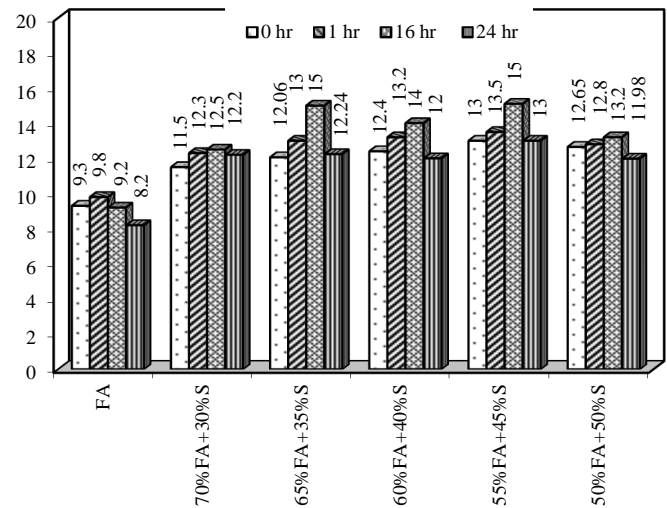


Fig. 11 Effect of Preconditioning Period on MDD of Fly ash and Fly ash–Waste Sludge Blend for Fresh Sample

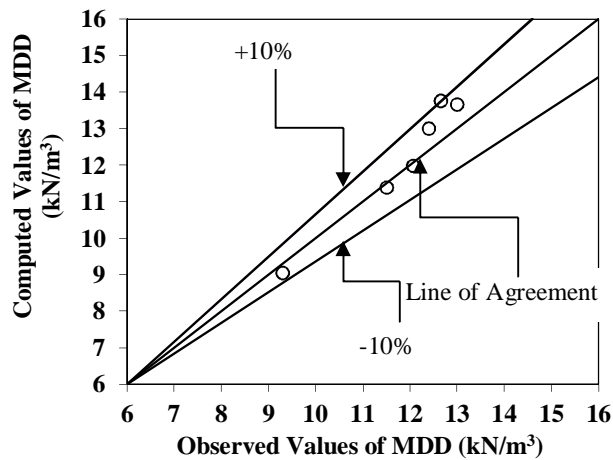


Fig. 12 Observed Versus Computed MDD Values

V CONCLUSIONS

Based on the above investigations, the following inferences are drawn:

- (i) Maximum dry density (MDD) and optimum moisture content (OMC) values of fly ash and fly ash–waste sludge used for structural fill may be taken as the average of at least three replicate compaction tests.
- (ii) Fresh sample of fly ash and fly ash–waste sludge for every compaction test may be used for determining the compaction properties. However, Preconditioning period is found to have influence on the MDD values of fly ash and fly ash–waste sludge. Therefore, a period equivalent to the expected time interval between wetting and compaction in the field may be adopted as preconditioning period for all types of fly ash and fly ash–waste sludge mix in the laboratory.
- (iii) In order to achieve good quality structural fills, modified Proctor MDD may be adopted as a benchmark value.
- (iv) The mix blend containing fly ash between 55%–65% and waste sludge blend between 35%–45% gives good results and may be adopted for geotechnical applications.
- (v) Thus, the outcome of this study will pave the way for utilizing these two industrial wastes (fly ash and waste sludge) for eco-friendly work.
- (vi) The relationship between MDD and OMC suggested by Bera *et al.* [16] for Dadri pond ash has been validated in case of Harduaganj fly ash.

It was also observed that the same equation may be extended to compute the MDD values of the fly ash-waste sludge combinations within the accuracy of $\pm 10\%$. Thus, this

relationship may be useful to the field engineers to check the reported MDD values in the field for the present fly ash and fly ash-waste sludge mixes as well.

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