Investigation of Stabilized Fly Ash-Lime Sludge Composite as a Base Course Layer for Pavements

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Abstract — In the present work, two potential industrial waste materials, Fly Ash (FA) and Lime Sludge (LS) that are generated in bulk quantities from thermal power plants and water treatment plants respectively and poses environmental hazards were stabilized using Commercial Lime (CL) and Gypsum (G) in order to make them suitable for use in Civil Engineering construction applications. Different compositions of FA, LS, CL and G (39 combinations) were studied and tested for Unconfined Compressive Strength (UCS), California Bearing Ratio (CBR) and Split Tensile Strength Test (STS). The quality of composite is judged based on these parameters and two composites (optimum mix 1, 95%FA+5%LS) and (optimum mix 2, 50%FA+50%LS) stabilized with 12%CL and 1%G have resulted well.

Keywords: Fly Ash (FA) and Lime Sludge (LS), Commercial Lime (CL), California Bearing Ratio (CBR), Split Tensile Strength Test (STS)

I. INTRODUCTION

Due to fly ash's advantageous physical, chemical, and other qualities, numerous researchers have previously proposed using fly ash in a variety of civil engineering construction projects. For instance, using Figure 1.2 as a guide, it has been investigated how to use fly ash in the production of cement and bricks , replace cement in mortar and concrete , build roads and embankments , use it as a light-weight aggregate , and use it in structural fills to reclaim low-lying areas. Furthermore, in order to cover all the major areas of fly ash application, specifications for pulverised fly ash for use as pozzolana in cement, mortar, and concrete were issued in 2003. Similarly, fly ash was used to revise the Indian Code of Practice for both plain and reinforced concrete. Guidelines for the use of fly ash in various pavement layers and road embankments have also been incorporated by the Indian Road Congress. Fly ash use in the cement and building industries has significantly expanded since 1999. In 1999, PPC's portion of the world's total cement production was roughly 21.8%; by 2014, that percentage had risen to 67%. As of right now, PPC accounts for close to 90% of India's total cement output, and further efforts are needed to maximise the use of fly ash in other applications . However, it might be realised that in the future, concrete and cement by themselves wouldn't be able to use larger amounts of fly ash; therefore, alternative pathways would need to be developed.

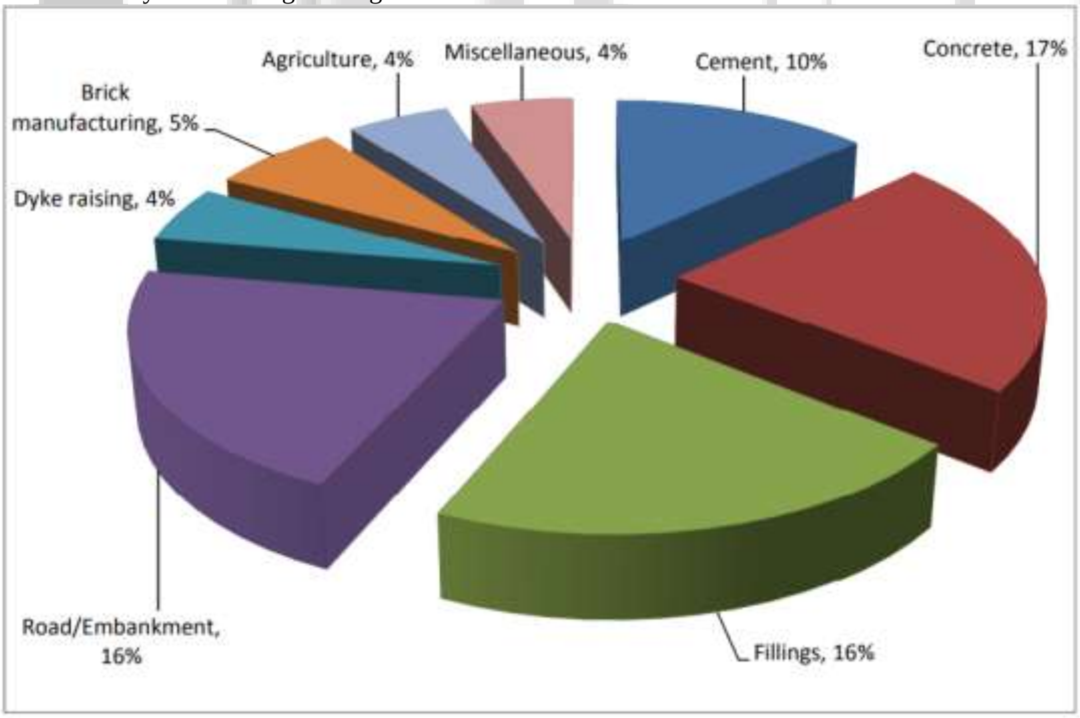

Fig. 1.1: Percentage utilization of fly ash

Sludge, another by-product of a water treatment facility, is also produced in large quantities. Water Treatment Plant Sludge (WTPS) is the residue left over after different water treatment procedures as chemical coagulation, flocculation, settling, and water softening. Aluminium salts [Al2(SO4)3.18H2O], ferric ion salts [FeCl3.6H2O], ferrous iron salts [FeCl2, FeSO4.7H2O], and calcium hydroxide [Ca(OH)2] are the chemical products that are frequently employed to treat water. When these chemical compounds are added to water for treatment, a sludge that is high in lime, iron, or aluminium is produced. The chemicals used to clean the raw water determine the makeup of the sludge. Sludge (based on ferric and alum) has been identified for use in a number of application areas, and it has been noted that it can be utilised to make construction blocks, cement, and bricks. Sludge based on alum and ferric acid has been utilised to recover metals, however it was discovered to be costly. Additionally, it had been used to agricultural fields as manure and utilised in the process of stabilising the soil. These days, the majority of water treatment facilities also soften the water, which produces lime sludge through the coagulation and softening processes. As a result, the large-scale production of lime sludge requires management and use.

Lime sludge is also produced by numerous other industries, including paper, acetylene, sugar, fertiliser, sodium chromate, and soda ash. The output of lime sludge from all sources was estimated to be 10 million tonnes annually in the CPCB report 2011, but the utilisation ratio was less than 10%. Research has demonstrated that lime sludge from the paper industry can be used (dry basis) as part of the raw mix to make cement clinker. Consoli and Saldana conducted recent investigations on the use of fly ash from thermal power plants and lime sludge from acetylene manufacturers to create high compressive strength, environmentally friendly bricks.

While a great deal of prior research has recommended the use of both fly ash and lime sludge in Civil Engineering Construction projects, combining the two by-products could offer a novel approach to using both simultaneously. Additionally, since FA is no longer a waste product, using a mix of FA and LS will prove to be more cost-effective than using solely FA. The pavement industry is a potential application for these by-products, since it offers the chance to use large amounts of fly ash and lime sludge as base or subbase course layers. However, it should be mentioned that the two chemically inert materials can be used for strengthening and cementing when they have stabilised due to pozzolanic activity. External stabilisers, including gypsum and commercial lime, are utilised to keep the FA and LS mixture stable. After stabilisation, the material's potential usage as a pavement base course or subbase course layer won't be known until it passes quality control inspection during laboratory testing and reaches the necessary stiffness and strength parameters as outlined in different codes.

II. LITERATURE SURVEY & BACKGROUND

Ghosh and Subbarao studied the physicochemical and microstructural developments of a low-lime fly ash modified with 6% and 10% lime and 1% gypsum. The strength of fly ash, stabilized with 10% lime and 1% gypsum, has reached a value of 6,307 kPa at 3 months' curing, i.e., 36.7 times the strength of untreated fly ash. The permeability has reduced to 10-7 cm/s due to the reduction in interconnectivity of the pore channels of the hydration products.

Kaniraj and Gayathri studied two Indian fly ashes stabilized with different content of cement for different curing period and revealed that the rate of increase in strength was high up to 14 days, and starts decreasing drastically between 28–90 days, and after 90 days no substantial change recorded in strength.

Kumar and Raju made attempts to investigate the stabilization process with model test tracks over expansive subgrade in flexible pavements. Unstabilized fly ash and fly ash stabilized with cement and lime was laid as subbase over sand and expansive soil and cyclic plate load tests were carried out on the tracks. The maximum load carrying capacity was obtained for stabilized fly ash subbase compared to untreated fly ash subbase. For sand subgrade the total deformation decreased by 52.73% at 500 kPa for treated lime-cement fly ash subbase as compared to untreated fly ash subbase whereas for expansive soil subgrade the decrease was 65%. In case of field stretches, the total deformation at 500 kPa was decreased by 52.68 % on sand subgrade whereas 72.86% on expansive soil subgrade for treated lime- cement fly ash subbase when compared to untreated fly ash subbase

III. OBJECTIVE

1) Development of high strength composite using different combination of fly ash and lime sludge along with stabilizing agents, commercial lime and gypsum and finding the optimum mix composite.
2) Study the durability and toxicity characteristics of the optimum composites and its further study on strength and ductility properties using polypropylene fibers.
3) Utilizing reliability based approach in developing design charts to estimate the total thickness of flexible pavement in a given environment of uncertainty in input design parameters such as design traffic load (MSA) and shear strength of soil (CBR).

IV. RESULT

A. Stabilization of fly ash-lime sludge with different content of stabilizer

1) Compaction Characteristics

Table 4.1 displays the moisture density relationship for the addition of lime sludge (20% to 60%) to the fly ash mixtures stabilised with gypsum and lime. It was shown that adding lime sludge to a mixture enhances its density and decreases its corresponding moisture content, regardless of the stabiliser content. The maximum dry density values of all composite materials fell at a specific fly ash-lime sludge content, and the optimum moisture content increased as the lime level increased (Figures 4.25, 4.26). It supports related findings for fly ash, soil, and lime combinations.

Mix details	MDD	OMC
(80FA+20LS)+4CL+1G	1451	30
(80FA+20LS)+8CL+1G	1443	32
(80FA+20LS)+12CL+1G	1435	33
(70FA+30LS)+4CL+1G	1464	30.5
(70FA+30LS)+8CL+1G	1458	31.5
(70FA+30LS)+12CL+1G	1451	32
(60FA+40LS)+4CL+1G	1498	31.5
(60FA+40LS)+8CL+1G	1495	31
(60FA+40LS)+12CL+1G	1480	31.5
(50FA+50LS)+4CL+1G	1544	30
(50FA+50LS)+8CL+1G	1532	30.4
(50FA+50LS)+12CL+1G	1525	32
(40FA+60LS)+4CL+1G	1558	28.5
(40FA+60LS)+8CL+1G	1542	29.3

(40FA+60LS)+12CL+1G	1537	29

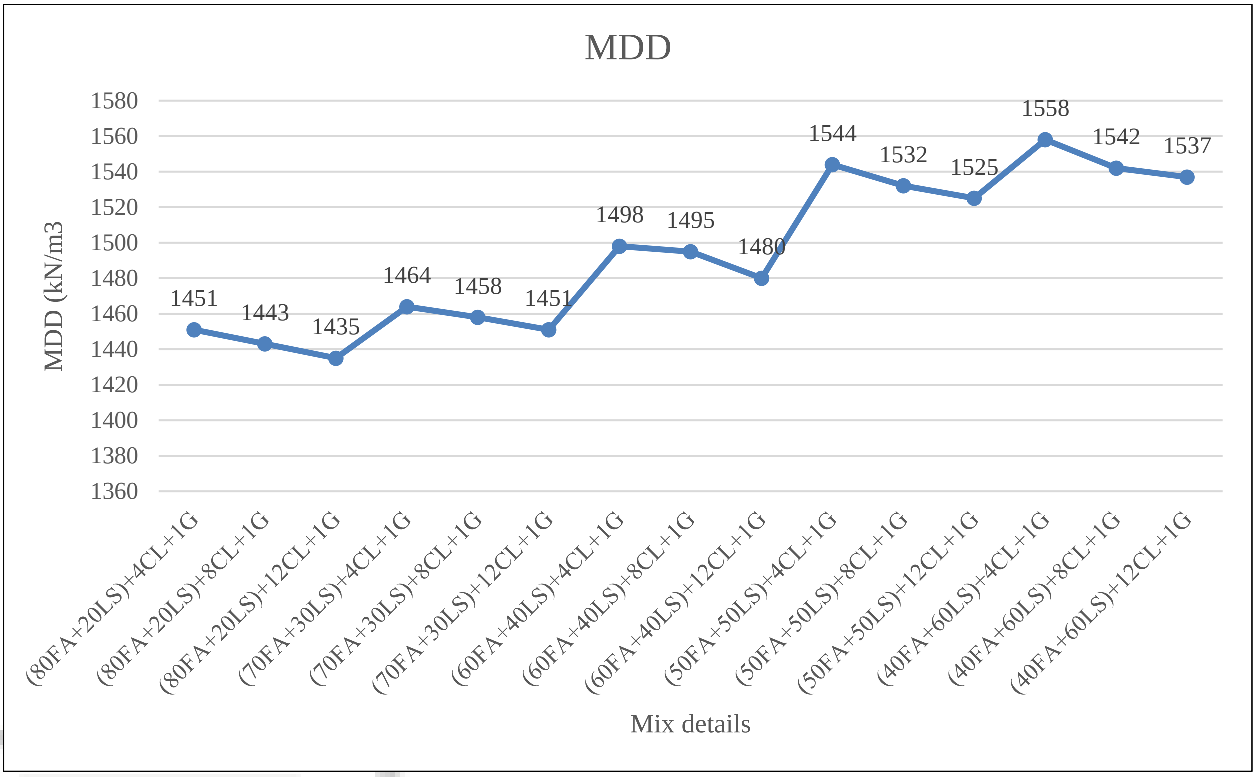

Fig. 4.1: Variaton of MDD of stabilized fly ash with lime sludge content

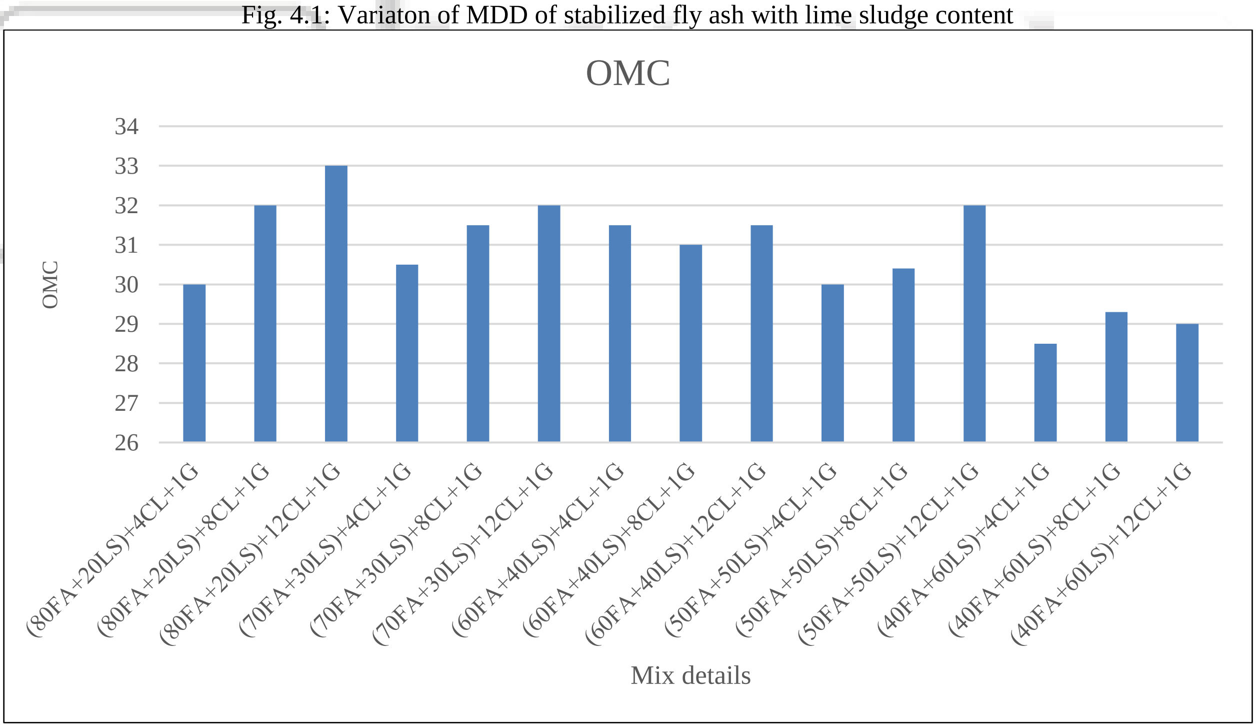

Fig. 4.2: Variaton of OMC of stabilized fly ash with lime sludge content

2) *Unconfined compressive strength*

SN	Mix details	UCS, kPa	
		7day	28 day
1	(80FA+20LS)+4CL+1G	950	2800
2	(80FA+20LS)+8CL+1G	1000	3300
3	(80FA+20LS)+12CL+1G	1100	4200
4	(70FA+30LS)+4CL+1G	975	2900
5	(70FA+30LS)+8CL+1G	1020	3400
6	(70FA+30LS)+12CL+1G	1200	4400
7	(60FA+40LS)+4CL+1G	1220	3100
8	(60FA+40LS)+8CL+1G	1280	3700
9	(60FA+40LS)+12CL+1G	1350	4600
10	(50FA+50LS)+4CL+1G	1450	3700
11	(50FA+50LS)+8CL+1G	1500	4400
12	(50FA+50LS)+12CL+1G	2150	5800
13	(40FA+60LS)+4CL+1G	1000	3300

14	(40FA+60LS)+8CL+1G	1050	3800
15	(40FA+60LS)+12CL+1G	1300	4600

Table 5.3: UCS for different fly ash-lime sludge mix after 7 & 28 days of curing

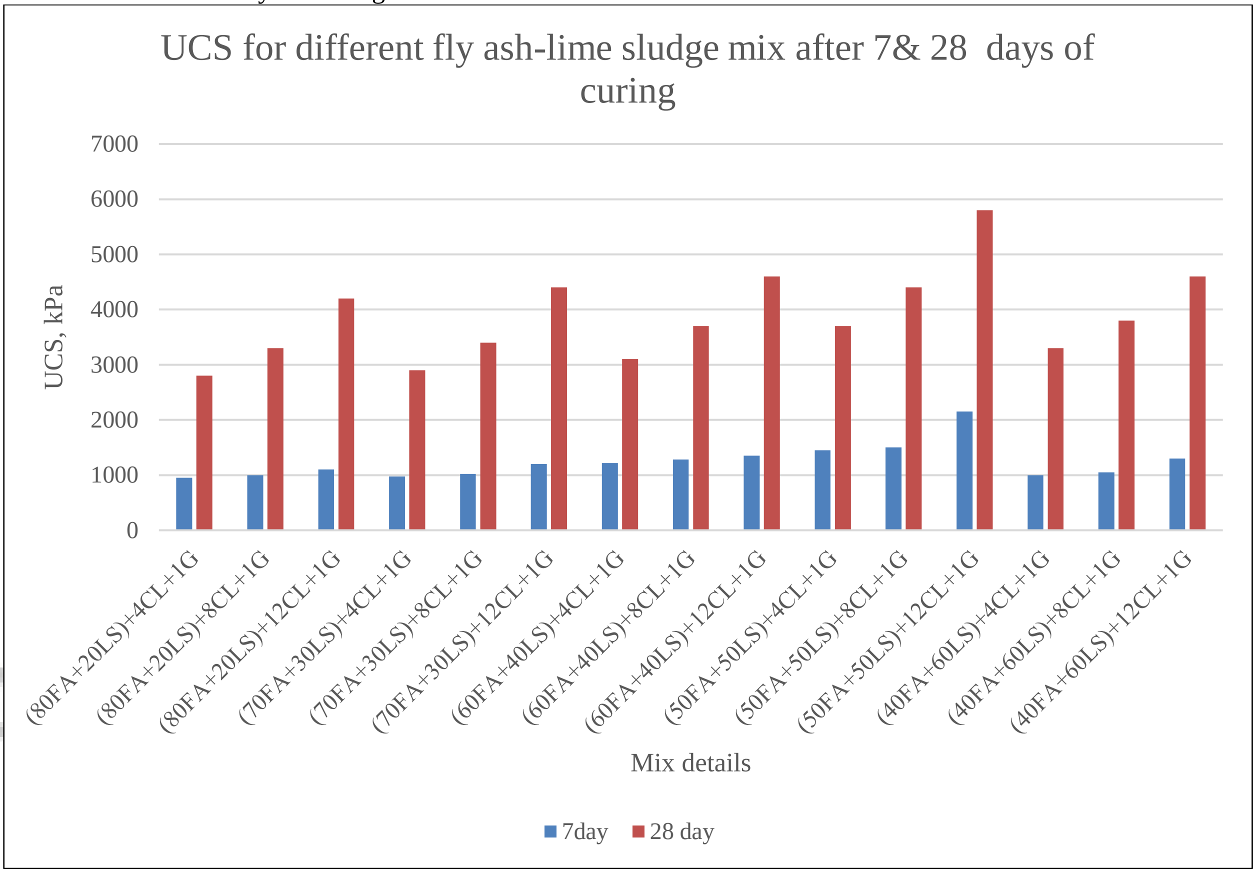

Fig. 4.4: UCS for different fly ash-lime sludge mix after 7 &28 days of curing

Above Figures display the strength curves of the composites for various curing times. It is clear from these curves that the unconfined compressive strength rises as the lime concentration does. Pozzolanic reaction products, such as calcium silicate hydrate (C-S-H) and calcium aluminate hydrate (C-AH), are created when lime is hydrated. These compounds fill the empty space and bond the particles together, giving the mass strength. An increase in the amount of lime in the mixture results in a greater quantity of reaction products, which improves particle binding. When lime sludge is added while maintaining a consistent lime concentration, there is also a noticeable increase in strength. When lime sludge is added to fly ash mixes, the mixture becomes well-graded and has a higher compacted density.

3) *California Bearing Ratio (CBR)*

SN	Mix details	CBR value, %	
		Unsoaked, 7 days curing	Soaked, 7 days curing
1	(80FA+20LS)+4CL+1G	39	27
2	(80FA+20LS)+8CL+1G	49	32
3	(80FA+20LS)+12CL+1G	55	38
4	(70FA+30LS)+4CL+1G	43	30
5	(70FA+30LS)+8CL+1G	54	35
6	(70FA+30LS)+12CL+1G	58	40
7	(60FA+40LS)+4CL+1G	44	33
8	(60FA+40LS)+8CL+1G	56	40
9	(60FA+40LS)+12CL+1G	59	41
10	(50FA+50LS)+4CL+1G	49	40
11	(50FA+50LS)+8CL+1G	57	43
12	(50FA+50LS)+12CL+1G	63	46
13	(40FA+60LS)+4CL+1G	49	35
14	(40FA+60LS)+8CL+1G	52	37
15	(40FA+60LS)+12CL+1G	55	39

Table 5.4: Unsoaked, soaked 7 days cured CBR values for different combinations

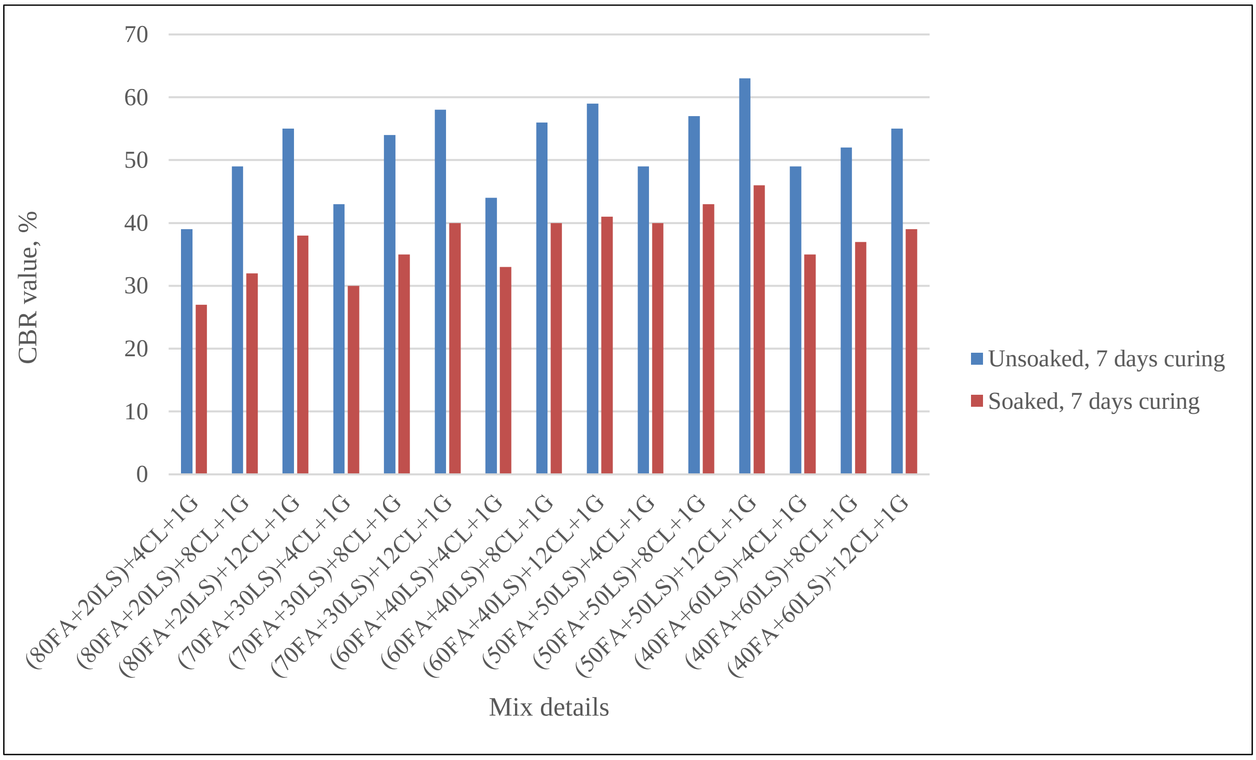

Fig. 4.4: Unsoaked, Soaked 7 days cured CBR values for different combinations

V. Conclusion

The results of experiments conducted on various ratios of stabilized FA-LS mix compositions show that an equal ratio (1:1) FA-LA sludge mix stabilized with 12% commercial lime and 1% gypsum had a maximum strength of 5.87 MPa and was chosen as the ideal composite.

References

[1] D. Ravikumar, S. Peethamparan, and N. Neithalath, "Structure and strength of NaOH activated concretes containing fly ash or GGBFS as the sole binder," Cement and Concrete Composites, vol. 32, no. 6, pp. 399-410, 2010.
[2] M. Nattapong, J. Chai, N. Charin, and S. Vanchai, "Effects of binder and CaCl2 contents on the strength of calcium carbide residue-fly ash concrete," Cement and Concrete Composites, vol. 33, no. 3, pp. 436-443, 2011.
[3] S. B. Shafique, T. B. Edil, C. H. Benson, and A. Senol, "Incorporating a fly ash stabilized layer into pavement design," in Proceedings of the ICE - Geotechnical Engineering, vol. 157, no. 4, pp. 239–249, 2004.
[4] I. Kourti and C. R. Cheeseman, "Properties and microstructure oflight weight aggregate produced from lignite coal fly ash and recycled glass," Resources, Conservation and Recycling, vol. 54, no. 11, pp. 769-775, 2010.
[5] IRC, SP 72, Design of flexible pavements for low volume rural roads, Indian Roads Congress, New Delhi, 2007
[6] IRC: 37. Tentative guidelines for the design of flexible pavements, Indian Roads Congress, New Delhi, 2012.
[7] P. Thongsanitgarn, W. Wongkeo, A. Chaipanich, "Hydration and compressive strength of blended cement containing fly ash and lime stone as cement replacement", Journal of Materials in Civil Engineering, vol. 26, no. 12, pp.101-109, 2013.
[8] Q. Wang, J.J. Lenhart and J.W. Walker, "Recovery of metal cations from lime softening sludge using Donnan dialysis", Journal of membrane science, vol. 360, no. 2, pp. 469-475, 2010.
[9] Central pollution control board CPCB, "Report on generation and utilization of industrial solid waste materials, New Delhi, 2011.
[10] N.C. Consoli, C.G. Rocha, S.B. Saldanha, "Coal Fly Ash – Carbide Lime Bricks: An Environment Friendly Building Product", Construction and Building Material, vol. 69, pp. 301-309, 2014.
[11] P.E. Glogowski, J.M. Kelly, R.J. McLaren and D.L. Burns, "Fly ash design manual for road and site applications", RP2422-2. Report prepared for Electric Power Research Institute, GAI Consultants, Monroeville, 1992.