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Geotechnical and Morphological Properties of Lime-stabilized Fly Ash Mine Overburden Mixtures for Subbase of Haul Road

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Abstract: Handling and the disposal of fly ash is a severe problem in the coal-based thermal power plants. Fly ash is a substantial by-product of the thermal power plants that adversely affect land, water, and air. It's a gainful usage is being explored continuously in many areas. The use of fly ash in the haul road construction for the opencast coal mines is one of the alternatives. This paper reports, detailed laboratory investigations executed with the lime stabilized fly ash-mine overburden mixes to assess their suitability for subbase of a mine haul road. The composite materials were prepared from fly ash, mine overburden, and lime at different proportions. Proctor compaction test, California bearing ratio (CBR) test were carried out at the various curing periods. The combination of the mix with 25% fly ash and 66% overburden, stabilized with9% lime, produced the highest possible compressive strength, and bearing ratio value as compared to that of the other mixes with curing, suitable for mine haul road construction. A laboratory test has been executed with different percentages of lime (3%, 6%, to 9%). Scanning electron microscopy (SEM), along with dispersive energy X-ray (XRD) analyses has been conducted at 7, 28 & 56 days cured samples. The experimental results showed that strength values of fly ash mine overburden and mixes up increased because of the lime treatment method.

Keywords: Fly ash; CBR; OMC; MDD; Lime; Mine Overburden, SEM, XRD

I. INTRODUCTION

The entire growth of a country mostly depends upon the power or energy generated along with consumed power as it is mainly pertaining to the industrialization of the country. India requires huge electric power to conform with the expectation of its residents of as well as its purpose to be an evolved nation by 2024 [1].

Fossil fuel (coal) continues to appreciate the dominant figure in session the demand for electrical power production, along with the pattern will proceed for the following 2 to 3 decades. Coal is the world's highest possible abundant and thoroughly spread nonrenewable fuel source. An estimation shows that near about 75% of India's complete installed electric power is thermal based, of which the portion of coal is around 90% [2].

Mining of the coal will certainly remain a major activity with the current advances in mining modern technology. The majority of the coal need is met from opencast surface mining because of its quickness along with the convenience of procedures. The existing coal production from opencast surface mines in India has to do with 390 (85%) Million Ton that will have to be improved significantly to satisfy the requirement for electric power [3]. The Mine haul roads are the lifeline of any opencast surface mine. The opencast surface mine economic situation relies proceeding the cost of haul road layout design, along with its routine maintenance in enhancement to various other aspects [4]. These haul roads are used by large earth-moving vehicles on surface mine.

The surface (opencast mines) of the haul road depends upon the behavior of the product below it. The haul road is of important relevance to exceed mine economics. The most solid construction materials for the base of these roads are compressed gravel or crushed rock and crushed stone mixtures [5]. A normal opencast surface coal mine has around 3 to 5 kilometers of permanent haul road, much larger ones having longer sizes and various other lumpy roads that are created either with overburden products or from in your area accessible product discovered near to the coal mine property. Some of those construction materials are concrete, asphaltic, sandstone, mudstone, etc. Crushed gravel is usually positioned on the top surface of the haul road. Asphaltic concrete needs a base layer with a CBR value of more than 80 and is extremely costly [6]. Usual construction component for haul road as gravels, sand, clay, etc. result only in filling the spaces as opposed to using total service to ground stability.

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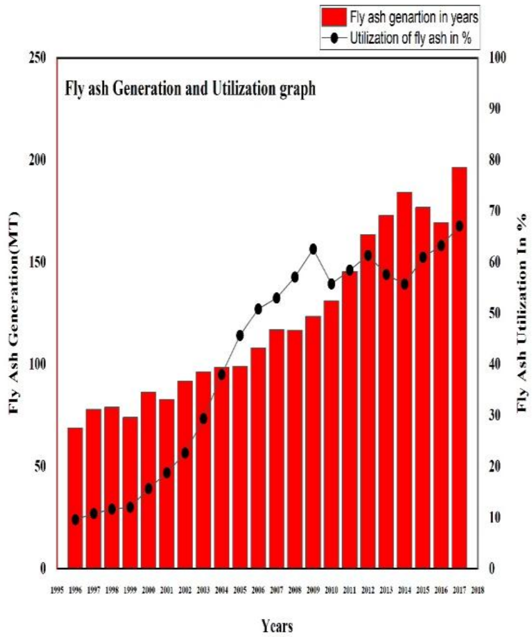

Fig. 1. Fly ash Generation and percentage of utilization

Frequently it is detected that the mine operating and routine maintenance rate of dumpers is considerably high in addition to haul road repair and maintenance cost. It causes lowered production, regular failure, crashes, accidental death threats, low employee motivation, etc. Nowadays' opencast mines are prepared to significant depths, commonly past industry's present expertise, experience, understanding and information base. In the previous 30 years, the carrying capability of hauling equipment e.g. Dumpers/trucks has grown-up from a minor 10 tons to 170 tons, 350 tons being projected at locations, requiring far better haul roads to carry heavy loads [7-8]. So, a much excellent mine haul road layout and design construction component would certainly attend to the rise loading as a result of higher abilities.

The existing yearly production of coal ashes worldwide is approximated at around six hundred million tons (MT), with fly ash composing approximately five hundred million tons (MT) at 75-80% of the overall ash generated. Currently, concerning 50% of the coal fly ash is gainfully used in India. Many analysts have reported the possible procedure of only fly ash, or soil mix with fly ash or fly ash and other admixtures for road construction. Shown in figure 2 the utilization of fly ash in multiple field. The lime stabilizing of soils or fly ash -soil mixes have been broadly described in the research study literature. Which includes the Physico-chemical processes of both equivalent briefs- to long-term responses. Our traditional estimation puts the unutilized fly ash inhabiting about 65,000 acres of land, which requires development in the usage percentage.

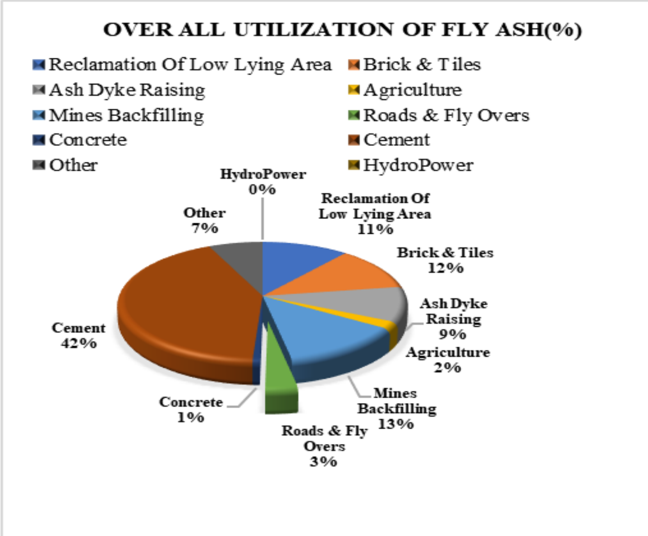

Fig. 2. Percentage Utilization of coal Fly ash in a significant field in India.

Lime stabilizing is commonly utilized to improve the durability and strength of road along with building components. Lime has been used alone or mixers with other products such as soil or coal ashes. The mineralogical properties of the soils affect the level of sensitivity with lime and the utmost strength that the stabilized layers create. Base stabilization is utilized for new road construction, and reconstruction of damaged routes and generally needs including in 3-9% lime by weight of the arid soil [8] In situ 'road mixing' is most frequently used for base stabilizing, although off-site 'central blending' can also be utilized. quicklime has been utilized enhanced the substances of soil/ accumulated mixtures completely depth recycling as per the soil stabilized lime (lime-treated soil) design handbook. In figure 3 shows the generation of Overburden removal (MT) in NCL year-wise data. Another figure 4 shows the percentage of overburden removal data in the NCL zone.

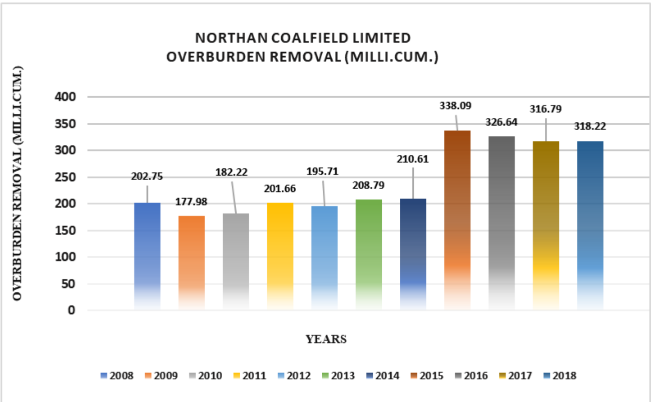

Fig. 3. Total Overburden removal (MT) in NCL

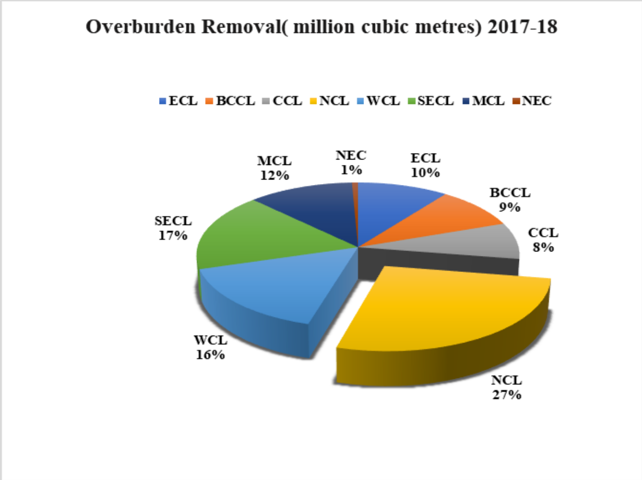

Fig. 4. Total percentage of Overburden generation in all mines of NCL

II. STUDY AREA

Jayant coal mine is an operating opencast mine in Northern Coalfields Limited. Since 1976, The Northern Coalfields Limited (NCL), a branch of Coal India Limited (CIL), is a prime supplier of non-coking coal, mostly power grade, in the nation. It runs coal mines in the states of M.P. and U.P. It is producing coal from different coal joints of Singrauli coalfields in the areas of Singrauli in M.P. and Sonebhadra in U.P. Mining operation is spread over one coalfield only, i.e., Singrauli. Singrauli coalfield is the northernmost participant of the central Indian coalfields.

Singrauli coalfield lies in between latitudes 23°47'& 24°12 'N and longitudes 81°40'& 82°52 'E. The coalfield is about 102 kilometers[9]. Long from west to east together with 45 kilometers. Vast from north to south occupying a total area of 2202 sq.km. The coalfield is mostly situated in the Singrauli region of Madhya Pradesh, and also, a small area of 80 sq.km in the extreme north-east depends on the district of Sonebhadra of Uttar Pradesh.

The mining of coal currently is constrained in the northeastern part of the Singrauli coalfield shown in figure 5.

Jayant Opencast Project lies in Singrauli Coalfields, which is positioned in the Singrauli district of Madhya Pradesh. It falls in within latitude 24° 6' 26.08 "& 24° 11' 40.86 "North as well as longitude 82° 38'2.01" & 82° 40' 55.64" East. (Survey of India toposheet no 63 L/12 of GSI). Jayant OCP has a lease location of 3177.171 Ha.

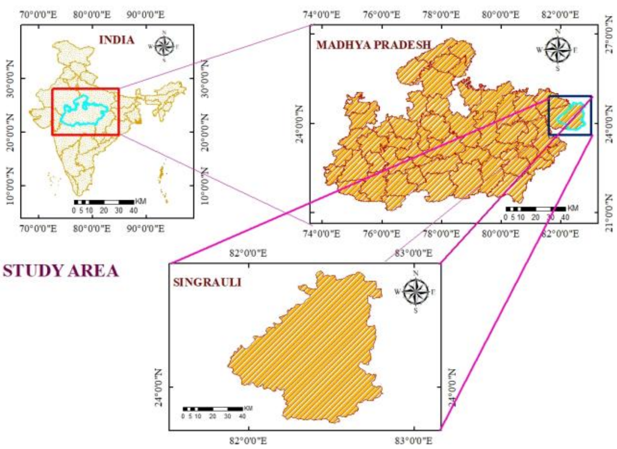

Fig. 5. Research Study Area and sample collection zone

III. MATERIALS AND METHODS

A. Fly Ash

B. The ash utilized in the research study was gathered in the completely dry state from electrostatic precipitators of CPP-II of Singrauli NTPC in Singuruli. The finer particles that outflow with flue gases are gathered as fly ash using electrostatic precipitators in hoppers and deposited. Gunny bags made of compact poly-coated cotton with 50kg volume each were utilized to accumulate the dry coal ash.

C. Lime

The additives selected were commercially easily accessible superior-top quality quick lime (produce: Rajasthan Lime, Goyal Udyog, India). The quick lime was utilized throughout the test program for strengthening the fly ash and mine overburden. The pureness of the lime was 75 %.

D. Overburden

In coal mining, overburden (also called waste material or spoil) is the material that lies overhead a zone that lends itself to economical exploitation, such as the soil, rock, and ecosystem that lies overhead a coal seam or ore body. Overburden is eliminated throughout surface mining; however, it often is not polluted with hazardous elements. The overburden removal data in India 2017-18 is given up in figure 3&4. The mine overburden(O/B) used in this research study was gathered from Jayant, opencast surface coal mine, at various specific locations. The running dumpers dump those materials and, dozers/spreaders are used to spread out the materials.

When dumpers dispose of those, dozers/spreaders are utilized to spread out the material. Specimens for tested were selected and accumulated that those signify the usual materials revealed in the surface mine. The sampling material was considered in the research laboratory separated to dispose of sand, pebbles, gravels, etc. the sampling materials were completely combined, enclosed for two hours for homogenize, and then kept in the poly pack used for research study and developments.

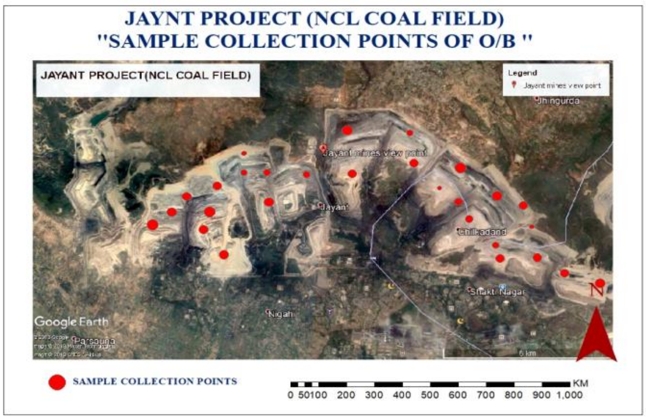

Fig. 6. Study Area and sample collection points in Jayant Mine

E. Sample Preparation

The soil chosen in those studies represents an essentially consistent product, Mine Overburden is an extremely heterogeneous configuration. The overburden product disposal is a major challenge to the mine manager. Additionally, has several disadvantages in its use as construction components of haul road along with branch roads. At these times, all methods are being experienced to increase making use of coal ashes. The research study aimed to advance the behavior of mine haul road along with fly ash replacing a component of the conventional sub-base component i.e., the overburden. Its objective was to assess the performance along with the development of composite material with fly ash and mine waste i.e. overburden compounds. Experiments were completed to a maximum of 50% fly ash addition in the overburden. The availability of free lime improves the pozzolanic venture of products. In this investigation, a differing portion of lime 3%, 6%, and 9% were utilized in preparing the fly ash-overburden combines. Weight sections of fly ash of 10%, 15%, 20%, 25%,30%,35% in order to 40%, 45%, 50% were used to blend with overburden and quick lime. The lime content percentage of 3%, 6%, and 9% by total weight of the complete mix was used in the research study. The Proctor compaction (heavy compaction) assessment was performed to identify the dry density and moisture content, mixtures of the coal ashes, overburden component, and lime as per IS code: 2720 (Component 8). Sample (FA+O/ B+LIME) for CBR evaluations were prepared at their corresponding OMC, and dry density (MDD). The CBR test specimens were prepared to utilize basic CBR mould of 150mm size as well as also 175mm altitude as per IS Code: 2720-Para 16 (1987) [11]. The test sample was stationary compressed in the mould the height of sample was preserved at 127mm. A spherical metal mould spacer disc of 148 mm diameter and also 47.7 mm elevation was utilized to compact the specimen.

Zeiss EVO (Japan) series Scanning Electron Microscope model EVO 18 was utilized to examine the morphology of the components and for XRD-analysis Miniflex600/Dtex Rigaku (Japan) used in CIF Research study lab of IIT (BHU) Varanasi.

In this observation, a differing part of lime percentage 3%, 6%, and 9% were utilized in preparing the fly ash-overburden combines. Weight segments of fly ash of 10%, 15%, 20%, 25%,30%,35% as well as 40%, 45%, 50% were used to combination with overburden and lime. The lime content of 3%, 6%, and 9% by percentage weight of the overall mixture was used in the research study.

Fig. 7. Collection of the samples in Jayant Mine

IV. RESULT AND DISCUSSION

A. Physical and Chemical Properties

The chemical and physical properties of mine overburden and fly ash are described in Table I & II. The specific gravity of fly ash is revealed to be a great deal much less than that of mine overburden, because of the arrival of cenospheres and plenty much less iron content material. The pH values show that fly ash is alkaline, and overburden is acidic depending on alkaline oxide content and free lime content material. The chemical Constituents of mine overburden and fly ash are existing in Table II.

The overburden consists of the sand-size segment with a much of non-plastic fines with low plasticity index. It is normally called improperly graded sand-silt mixtures and fit in to the SM community. The fly ash originates from Non-plastic inorganic coarse silt-sized fractions (MLN) group because it carries greater than 50% of fines negligible because of flocculation. The pH values display that fly ash is alkaline, moreover overburden is acidic relying upon alkaline oxide content and also free lime content. The chemical compositions of mine overburden and fly ash are supplied in Table II. The chemical composition of fly ash indicates that it has lots of less calcium content. Therefore, it's far categorized as "Class F" fly ash as per ASTM 618 standards. Table III delivers the MDD and OMC of the mixtures based upon compaction tests.

Table I. Chemical Composition of Coal Fly Ash (FA), Overburden(O/B) & Lime(L)

Constituents	Fly ash	Mine Overburden	Lime
SiO_2	53.98	49.56	1.98
Al_2O_3	34.19	28.98	0.87
Fe_2O_3	6.98	8.39	0.42
CaO	0.56	1.10	70.58
K_2O	1.43	0.42	0.98
MgO	0.67	1.37	3.20
TIO_2	0.52	0.68	---
Na_2O	0.3	---	0.12
P_2O_5	0.12	---	0.04
SO_3	---	---	0.26
LOI	1.55	9.5	21.55

Table II. Consistency Limits & Grain Size Distribution of Fly Ash & O/B

Property	Fly ash	Overburde n
Specific gravity	2.13	2.62
Consistency limits		
Liquid limit (%)	31.47	26.28
Shrinkage limit (%)	----	15.87
Plastic limit (%	Non-plasti c	16.05
Plasticity index (%)	----	10.23
Particle(grain) size analysis (%)		
Gravel (>4.75 mm)	----	08.52

Sand (4.75 mm – 0.075 mm)	21.67	30.45
Silt (0.075 mm – 0.002 mm)	75.41	49.78
Clay (<0.002 mm)	2.92	11.25
pH	7.23	5.12

B. Compaction Characteristics

The modified Proctor (heavy compaction) compaction assessment was conducted to figure out the MDD including the OMC of the overburden component based on IS Code: 2720 - Part 8 (ASTM D 1557) [12]. The take a look at specimen to become closely compacted inside the iron mould in 5 layers making use of a rammer of 4.9 kg mass with a fall of 450 mm through giving 25 blows per layer. Shown in figure 8.

Fig. 8. The modified Proctor compaction test performed in a research lab

Proctor Compaction assessment is the procedure of enhancing the dry density of the product through the application of geo-mechanical power just like rolling, vibration, and tamping. It is attained by forcibly the grains nearer with a decrease in air gaps (air voids). The OMC is actual moisture content by which the highly compressed product gets to the highest dry density (MDD) of compacted elements.

The compaction qualities of components as mine overburden and fly ash were performed to figure out the OMC and MDD. The MDD of coal ash was less than that found for mine overburden because of reduced specific gravity along with non-cohesive in character. Because of the simple reality that particles selves are cenospheres or hollow and holds a substantial amount of water inside, fly ash has greater optimum moisture content. The Proctor Compaction curve of fly ash is practically flat along with shows it's insensible to moisture variation. The MDD of fly ash is much less than that of overburden due to less iron content and the specific gravity of the fly ash. The MDD of mine overburden and coal ash were 2026 kg/m3 and 1356 kg/m3 exclusively. Corresponding values for OMC were 9.6% and additionally 21.85%, respectively, shown in figure 9 & Table III. The low-density cost of fly ash resulted from the high moisture content unlike the overburden, which has much less water content material.

The compaction characteristics of untreated (raw materials) composites diverse between 2008 kg/m3 to 1696 kg/m3, shown in figure 10 & Table III. However, the trend is reversed for the OMC (optimum level of moisture content) & holding capacity of the compounds. The coal ash percentage has enhanced the values for OMC also improved, shown in figure 11-13 & Table III. The sampling actions changed when lime added in 3,6,9% proportions. The dry density (MDD) values of all compound materials reduced, in other hand OMC enhanced with an increase in lime content. shown in figure 11-13 & Table III.

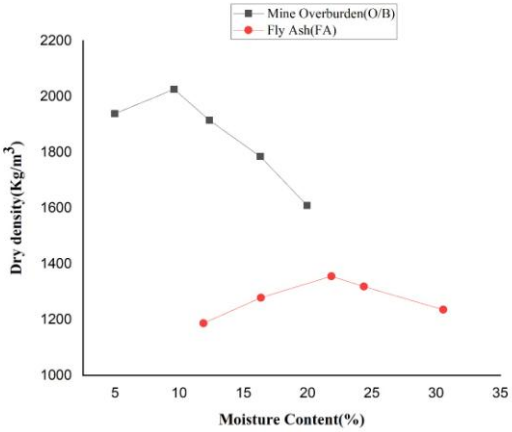

Fig. 9. The dry density and moisture content Compaction curves for fly ash & overburden

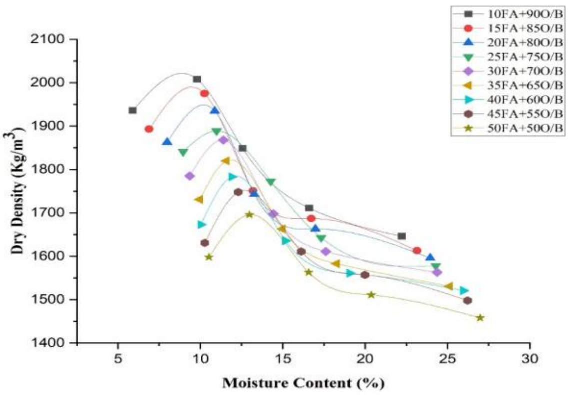

Fig.10. The dry density and moisture content Compaction curves for Untreated Composites

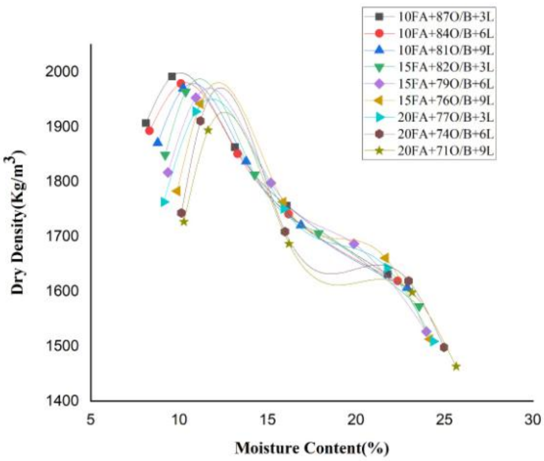

Fig. 11. The dry density and moisture content curves for Compaction composites containing of 10,15 & 20% fly ash

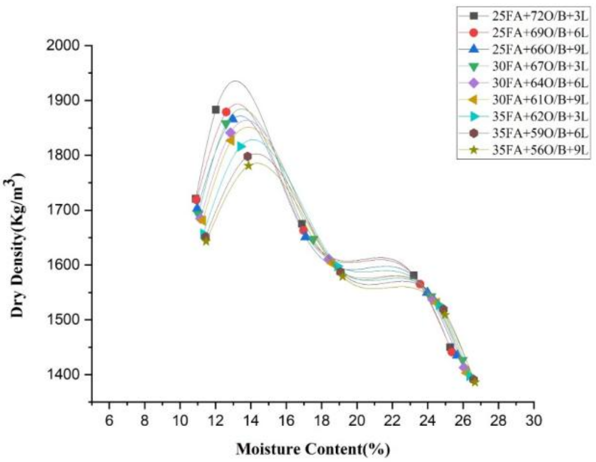

Fig. 12. The dry density and moisture content curves for Compaction composites containing of 25,30 & 35% fly ash

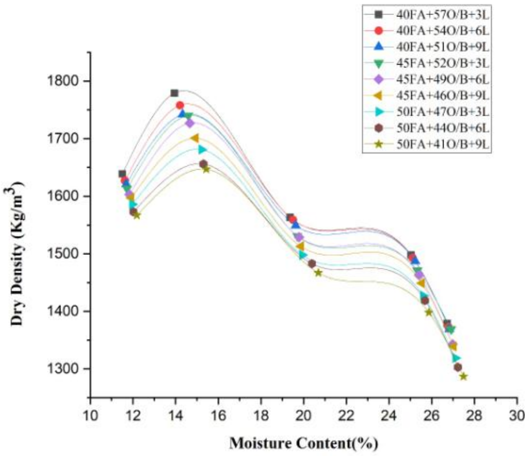

Fig. 13. The dry density and moisture content curves for Compaction composites containing of 40,45 & 50% fly ash

Table III. The data of Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) Values

Mixture	MDD (kg/m^3)	OMC (%)
Mine Overburden	2026	9.6
Fly ash	1356	21.85
FA+OB		
10+90	2008	9.80
15+85	1975	10.25
20+80	1935	10.87
25+75	1889	10.98
30+70	1868	11.40
35+65	1820	11.58
40+60	1783	11.89
45+55	1748	12.30
50+50	1696	12.98
FA+OB+LIME		
10+87+3	1992	9.96
10+84+6	1979	10.10
10+81+9	1970	10.23
15+82+3	1964	10.37
15+79+6	1953	10.95
15+76+9	1942	11.20
20+77+3	1928	10.93
20+74+6	1911	11.21
20+71+9	1894	11.64
25+72+3	1883	12.02
25+69+6	1879	12.61
25+66+9	1866	12.97
30+67+3	1858	12.60
30+64+6	1841	12.85
30+61+9	1827	12.89
35+62+3	1816	13.40
35+59+6	1798	13.82
35+56+9	1781	13.87
40+57+3	1779	13.95
40+54+6	1758	14.21
40+51+9	1742	14.33
45+52+3	1740	14.60
45+49+6	1727	14.67
45+46+9	1701	14.94
50+47+3	1681	15.22
50+44+6	1656	15.31
50+41+9	1647	15.44

C. California Bearing Ratio (CBR)

The California bearing ratio test (CBR) is a penetration assessment to examine the mechanical strength of road construction materials. This test was performed based on the IS Code: 2720-Para 16 [13]. The test samples were extremely compressed to 95% of maximum dry density (MDD) in the mould for the California bearing ratio test, shown in figure 14. After compaction of the specimens were cured for 7days (3 days curing period of moist + 4 days period of soaking) to 28 days (24 days curing period of moist + 4 days period of soaking) along with 56 days (52 days curing period of moist + 4 days period of soaking) before testing. CBR assessments were performed at the end of the corresponding curing period interval. Two extra disks, each and every weight 2.5 kg, were placed on top of the specimen model, and a plunger, size 50 mm in diameter, was utilized to penetrate the test sample at the rate of 1.25 mm/min throughout the CBR evaluation.

Fig.14. The experimental analysis setup for CBR test

The variant of CBR value through the mixtures of mine overburden & fly ash or fly ash overburden and lime for both soaked and un-soaked situations was revealed.

The additives like cement or lime improve the strength of the soil or fly ash. CBR values were calculated for fly ash-overburden material supported with lime shown in figure 15. Quick Lime was included amongst 3% to 9% to detect the consequence of lime [14]. Therefore, quick lime was included, different composition revealed considerable improvement in CBR values shown in Figures 16,17 & 18. The highest CBR value gotten was for composite with 25% FA +66% O/B + 9% lime at 56 days period of curing at 225 MPa shown in figure 18. The comparable values for various composites with 30% as well as 35% fly ash material were near about the same. It shows that there occurs an extreme limit for coal fly ash component to add to the improved the CBR value shown in Figures 16,17 & 18. The final results reveal that treating of dry ash content has a strong result on the bearing capability of the final compound. It is detected from the final results that the CBR values improved from 48% to 153% and 113% to 195% at 7 and 28 days the same 131% to225% at 56days of curing, respectively, shown in figure 16,17 & 18. Therefore, the CBR value increased when the percentage of lime and curing period is increase simultaneously.

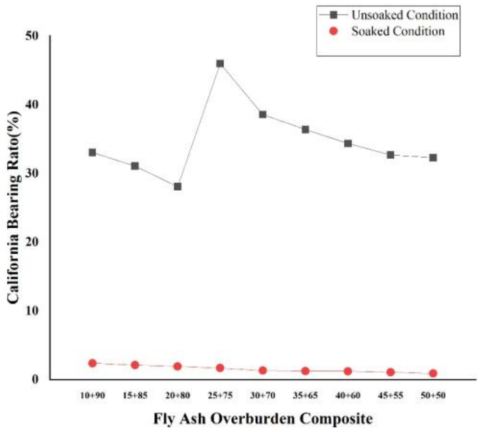

Fig.15. Variant of CBR with the add-on of fly ash to mine overburden

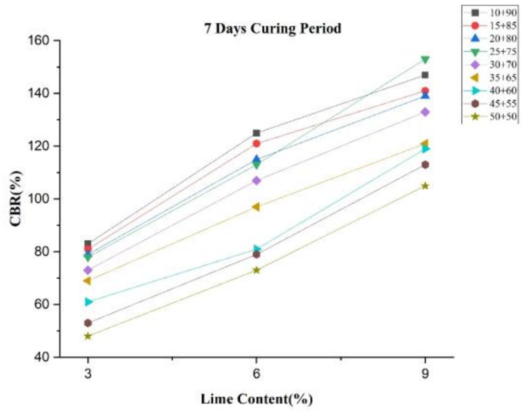

Fig. 16. Impact of lime % on CBR behavior of compounds at 7 days curing period.

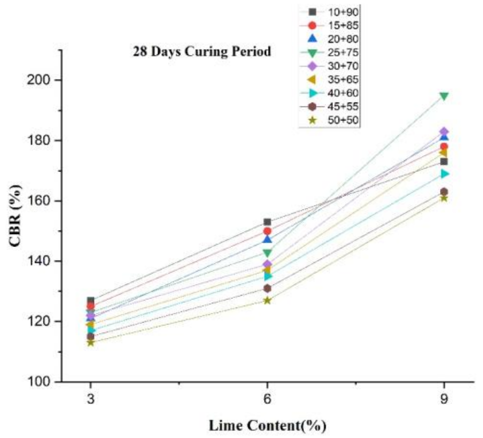

Fig. 17. Impact of lime % on CBR behavior of compounds at 28 days curing period.

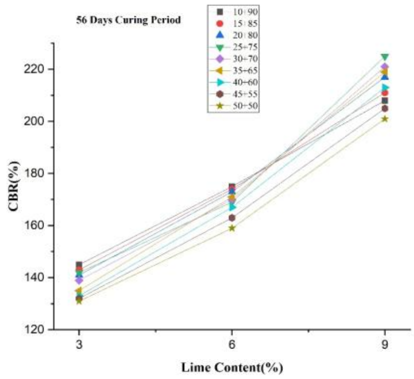

Fig. 18. Impact of lime % on CBR behavior of compounds at 56 days curing period.

CBR gain factor is the strength improvement because of the addition of different lime % in the treated compounds concerning that of untreated substances. The highest gain point value was acquired for blended material (25%FA +66% O/B) +9%L found at 67 in 56 days cured period. Similarly, the minimum gain point was definitely for the (10%FA +87%O/B+3%L) composite at the soaked condition. Displayed in in figure 19,20 & 21.

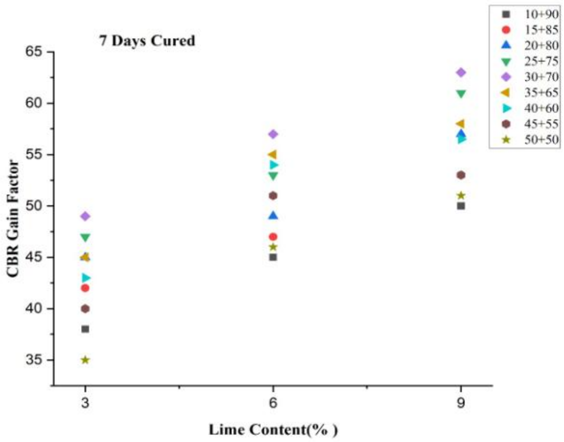

Fig. 19. Impact of Lime % in CBR Grain for all compounds at 7 days curing period.

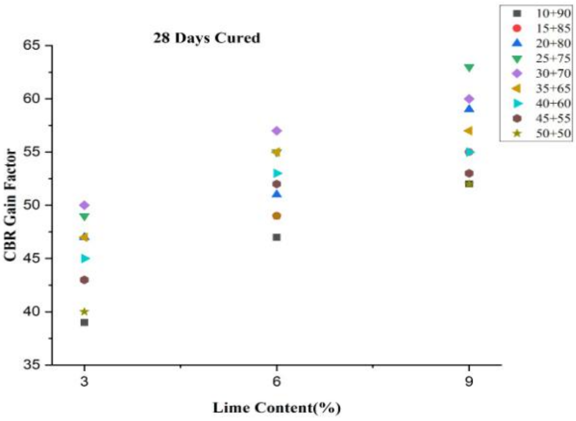

Fig. 20. Impact of Lime % in CBR Grain for all compounds at 28 days curing period.

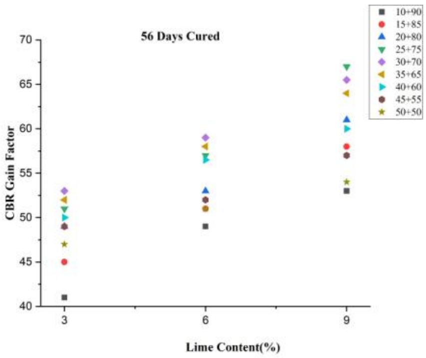

Fig. 21. Impact of Lime % in CBR Grain for all compounds at 56 days curing period.

D. Microstructural Behavior

Scanning Electron Microscopic (SEM)

The microstructural characteristics of coal fly ash, mine Overburden, and lime Mixtures were studied by scanning electron microscopic approaches in Central Instrument Facility (CIF) Research Lab IIT(BHU) Varanasi. A small-sized part of the material was held in the oven at 105°C for 24 hours for drying out. The sample was connected to a sampling holder. \ Zeiss EVO series Scanning Electron Microscope version EVO 18 was used to assess the morphology of the materials. The SEM (scanning electron micrograph) of coal fly ash, Overburden, along with quick lime at 5000 times magnifying [14]. It revealed that smooth, along with spherical particles of various size ranges were present in the fly ash & mixes. It suggested that irregular and angular particles of various dimension ranges existed in the fly ash, Overburden, and lime combinations. The segment of particles is shown in figure 22, SEM Image of (25FA+66O/B+9LIME) reveal that the size of reduced than 4 microns was existing, as well as some particles of size 8 microns, were detected. The SEM Image of fly ash, Overburden, and lime reveal that it displays a smooth surface, rugged, and angular shape Surface.

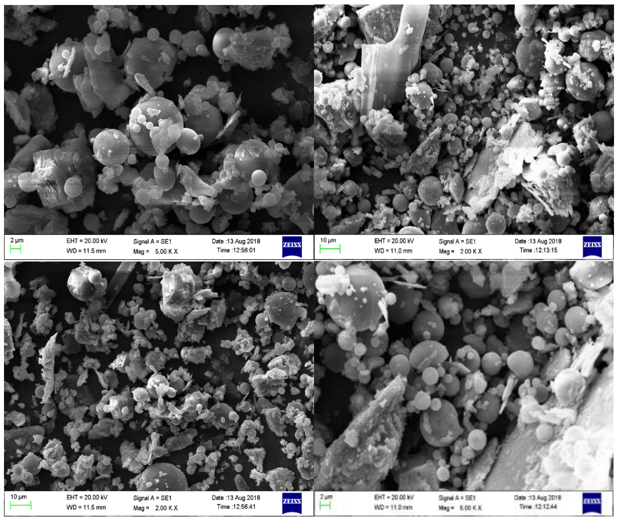

Fig. 22. SEM Image of (25FA+66O/B+9LIME)

- **X-ray Diffraction (XRD)**

It is recognized from micro-analyses that the fresh cementitious substances such as calcium aluminate hydrate (C-A-H), calcium silicate hydrate (CS-H), to calcium aluminate silicate hydrate (CASH) [shown in figure 23]were developed around the mixture of fly ash, overburden and lime elements therefore of the pozzolanic response during 56 days curing period [15]. These hydration materials refilled the pore spaces and preserved a bond between fly ash spheres along with mine overburden particles. It validates that the raise in lime material generates a densified interlocking network coupled with the strength development, furthermore depends on the variety of hydration products in addition to their interlocking structures. The strength growth is affected by the cementitious gel (calcium silicate hydrate gel (CS-H calcium aluminate hydrate gel (C-A-H)) formed and, accordingly, by the amount of lime consumed. The XRD pattern of the fly ash, overburden, and lime mixtures stabilized with 3%.6%and 9% lime shown in figure 23.

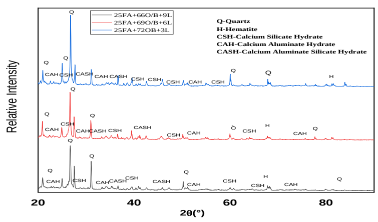

Fig. 23. XRD patterns of (25FA+66OB) stabilized with 9, 6, and 3 % lime

V. CONCLUSION

The following conclusions are taken from the existing research study.

1) The fly ash and overburden stabilized with lime show stimulating potential to be utilized in haul road development. The laboratory experimental observation discloses that the dry fly ash and mixtures can be used capably in bulk as a base & sub-base component in mine haul road.

2) The mine overburden fly ash with lime at the different ratio appearance the good strength to be used in mine haul road layout and design. In them (25FA+66O/B+9Lime) has provide maximum strength in the mixers.
3) The usage of mine overburden and fly ash combine with lime would certainly have a considerably higher bearing capacity and therefore minimized strain. The maximum dry density (MDD) values of all compound products decreased, and also optimum moisture content (OMC) raised with a higher in lime substance.
4) The mixes up of quick lime in the curing of specimens enhance the California bearing ratio (CBR) value substantially. With an enhancement in fly ash material, the CBR value increases up to a specific percentage after that decreases because of classifications class F coal ash.
5) The morphology (microstructure) all of the blends showed the development of hydrated gel at 56 days curing period. The air voids in between the particles were filled by expanding hydrates with the curing period. Microanalysis validated the creation of new cementitious compounds for example calcium silicate hydrate gel (CS-H),
 calcium aluminate silicate hydrate gel (CASH) along with calcium aluminate hydrate gel (C-A-H), which causes an improvement in the bearing ratio of the component gradually.

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