Utilization of High Calcium Fly Ash as Filler Materials in Concrete Bituminous Mixes for Flexible Pavement

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Abstract— A bituminous paving mixture is a mixture of coarse aggregate, fine aggregate and bitumen mixed in suitable proportion to result strong and durable mix to withstand traffic load. In this paving mix, normally cement is used as filler material. A study has been carried out in this study to explore the use of high calcium fly ash, a by-product of a coal based thermal power plant in bituminous paving mixes. For comparison, control mixes with cement and has also been considered. Marshall Test has been considered for the purpose of mix design as well as evaluation of paving mixes. It is observed that the mixes with high calcium fly ash as filler exhibit marginally inferior properties compared to control mixes and satisfy desired criteria specified by a much higher margin. Hence, it has been recommended to utilize high calcium fly ash wherever available, not only reducing the cost of execution, but also partly solve the binding properties. The results obtained showed that the high calcium fly ash could improve the properties of bituminous mixes for flexible concrete.

Key words: bituminous concrete, Marshall Properties (flow value and stability), optimum bitumen content, high calcium fly ash, flexible concrete

I. INTRODUCTION

Aggregates bound with bitumen are conventionally used all over the world in construction and maintenance of surface course of a flexible pavement. The surface course normally comprises of bituminous mixtures comprising of coarse aggregate, fine aggregate and filler heated to suitable temperature, mixed thoroughly with heated bitumen at required viscosity and then compacted. The bituminous mix may be dense graded, gap graded or uniformly graded. Bituminous concrete (BC) is a well graded mixture containing coarse aggregate (50-60%), fine aggregate (40-50%), filler (5-6%), bitumen (6-10%) of total mass of mix. One of the major concerns of mix design of bituminous mix is the type and amount of filler used which may affect the performance of the mix. Various studies have been conducted to study the properties of mineral filler; generally the material passing 0.075mm IS sieve, to evaluate its effect on performance of asphalt paving mixture in terms of consistency, void filling, Marshall Stability and mix strength.

A number of studies have been made on use of different types of fillers in various types of paving mixes which are presented briefly below. Although the filler particles are small in size, it is well documented that filler exerts a significant effect on the characteristics and performance of asphalt concrete mixture. Good packing of the coarse aggregates, fine aggregates, and filler provides a strong backbone for the mixture (Zulkati et al., 2011). Higher filler concentrations result in stronger pavement attributable to better asphalt cohesively and better internal stability. However, an excessive amount of filler may weaken the mixture by increasing the amount of asphalt needed to coat the aggregates (Kandhal et al., 1998). In general, type of filler, type of stabilizer, amount of stabilizer affect not only optimum bitumen content (OBC) of paving mixes but also affect the property like Marshall stability, tensile strength, retain stability of mixes. Also OBC of dense graded mix is less than stone matrix asphalt (Brown and Mallick, 1994). An investigation on property of eight different types of mineral filler materials in Europe indicated that the filler quality does not affect the performance of mixture (Mogawer and Stuart, 1996). Waste marble dust obtained from shaping process of marble blocks and lime stone used as filler in hot mix asphalt and optimum bitumen content was determined by Marshall Test and it showed good result (Karaşahin and Terzi, 2007). Similarly a comparative study was done on SMA by taking basic oxygen slag as aggregate with PG 76-22 modified bitumen and lime stone as filler and chopped polyester fibre as stabilizer and SMA without fibre; concluded that modified SMA is superior compared to conventional SMA (Wu et al., 2007). SMA prepared with municipal solid waste incinerator (MSWI) fly ash as a partial replacement of fine aggregate or mineral filler and Basic Oxygen Furnace (BOF) Slag as part of coarse aggregate with polyester fibre of 6.35 mm in length obtained from recycled raw materials, PG 76-22 bitumen in the mix and performed Marshall and super pave method of design and found it's suitability for use in the SMA mix (Xue et al., 2009). Four types of industrial by-product wastes filler namely, limestone as reference filler, ceramic waste dust, coal fly ash, and steel slag dust increases the stiffness and fatigue life of Stone Mastic Asphalt (SMA) Mixtures (Muniandy and Aburkaba, 2011). Waste glass powder as mineral filler on Marshall Property of bituminous by comparing with bituminous where lime stone, ordinary Portland cement was taken as filler with varying content (4-7%). Optimum glass powder content was found 7%. By using glass powder as filler in bituminous its stability increases up to 13%, flow value decreases, density also decreases as compare to bituminous contains lime stone and cement filler (Jony et al., 2011).

From above literature it is found that very limited study has been done on dense graded mixes with fly ash and high calcium fly ash as filler. Fly ash is one of the major waste by-products of coal based thermal power stations. At places around such plants, fly ash is not only abundantly available, it finds little use, for which it creates serious waste disposal problems. High calcium contains about 43% of calcium. Due to high rate of calcium binding and aging properties also increase. Hence, in this study, an attempt has been made to explore the use of high calcium fly ash, which is mostly passing 0.075 mm sieve and has been considered to be filler in bituminous paving mixes by studying various fundamental engineering properties.

II. BITUMEN AND HIGH CALCIUM FLY ASH

A. Bitumen:

Bitumen is defined as "A viscous liquid, or a solid, consisting essentially of hydrocarbons and their derivatives, which is soluble in tri chloro-ethyelene and is substantially nonvolatile and softens gradually when heated. It is black or brown in colour &possesses waterproofing and adhesive properties. It is obtained by refinery processes from petroleum, and is also found as a natural deposit or as a component of naturally occurring asphalt, in which it is associated with mineral matte. The below figure shows the refined of bitumen materials.

Fig. 1: Refined Bitumen

Bitumen is manufactured from crude oil. Bitumen is obtained as the last residue in fractional distillation of crude petroleum. Crude petroleum is different molecular weights. In the petroleum refineries the individual components like LPG, naphtha, Kerosene, Diesel etc. are separated through the process of fractional distillation. The heaviest material obtained from the fractional distillation process is further treated and blended to make different grades of paving grade bitumen. The actual bitumen output can be controlled not only by selecting the appropriate crude but also by adopting varying processes in the refinery. The choice of process would depend on the availability of suitable crude, demand of the end products and total commercial viability of the complete refining process.

The function of asphalt pavements on any given road can be defined as:

(1) The roof of the road construction, preventing moisture from penetrating into the construction.
(2) A riding surface for the traffic and the users of the road.
(3) A structural layer in the construction.

B. Types of Bitumen:

Bitumen or bituminous binder available in India is mainly of following types.

1) Penetration Grade:

a) Bitumen 80/100:

The characteristics of this grade confirm to that of S 90 grade of IS-73-1992. This is the softest of all grades available in India. This is suitable for low volume roads and is still widely used in the country.

Fig. 2: Bitumen grade 80/100

b) Bitumen 60/70:

This grade is harder than 80/100 and can withstand higher traffic loads. The characteristics of this grade confirm to that of S 65 grade of IS- 73-1992. It is presently used mainly in construction of National Highways & State Highways.

c) Bitumen 30/40:

This is the hardest of all the grades and can withstand very heavy traffic loads. The characteristics of this grade confirm to that of S 35 grade of IS-73-1992. Bitumen 30/40 is used in specialized applications like airport runways and also in very heavy traffic volume roads in coastal cities in the country.

2) Industrial Grade Bitumen:

Industrial grade bitumen is also known as blown bitumen. This is obtained by blowing air into hot bitumen at high temperatures. Blowing hot air into bitumen at high temperatures results in structural changes in bitumen. Industrial grade bitumen is used in industrial applications and in water proofing, tar felting etc.

3) Cutback:

Cutback is a free flowing liquid at normal temperatures and is obtained by fluxing bitumen with suitable solvents**.** The viscosity of bitumen is reduced substantially by adding kerosene or any other solvent. Cutback has been used in tack coat applications.

4) Bitumen Emulsion:

Bitumen emulsion is a free flowing liquid at ambient temperatures. In bituminous emulsion, bitumen is disperse phase and water is continuous phase stability of emulsion is achieved by the use of an emulsifying agent contained in the aques phase Based on type of emulsifying used, the bituminous particles can be negatively charged or positively charged Emulsion having a negatively charged bitumen particles are called anionic emulsion and those having a positively charged particles are called cationic emulsions.

5) Modified Bitumen:

Modified Bitumen are bitumen with additives like tar and bitumen mixtures in which tar is utilise as an additive, rubberised tar and bitumen mixtures in which additive of small quantity of natural rubber vastly changes the properties of tar and bitumen to great advantage, Polymer

Modified Bitumen mixture in which plastics and elastomeric are used as bitumen modifiers. These additives help in further enhancing the properties of bituminous pavements.

6) Viscosity Grade Bitumen:

The new method of grading the product has now rested on the viscosity of the Bitumen (at 600C and 135 0C). The new grades have thus evolved with Nomenclature.

Grades	Minimum of Absolute viscosity, poise@ 60 C	Approximate penetration grade
VG 10	800	80-100
VG 20	1600	--------
VG 30	2400	60-70
VG 40	3200	30-40/40-50

Table 1: Bitumen grade

C. Bituminous Concrete Mix Design:

1) Overview:

The bituminous concrete mix design aims to determine the proportion of bitumen, filler, fine Aggregates, and coarse aggregates to produce a mix which is workable, strong, durable and economical. There are two types of the mix design [dry mix design and wet mix design].

2) Objective Of Bituminous Mix Design:

Main objectives of bituminous mix design are to find;

- Optimum bitumen content to ensure a durable pavement.
- Sufficient strength to resist shear deformation under traffic at higher temperature.
- Proper amount of air voids in the compacted bitumen to allow for additional compaction done by traffic.
- Sufficient workability and sufficient flexibility to avoid cracking due to repeated traffic load.

3) Requirements Of Bituminous Mixes:

Bituminous mixture used in construction of flexible pavement should have following properties;

- Stability and Durability
- Flexibility and Skid resistance
- Workability

D. Fly Ash:

Fly ash, also known as flue-ash, is one of the residues generated in combustion, and comprises the fine particles that rise with the flue gases. In an industrial context, fly ash usually refers to ash produced during combustion of coal. Fly ash is generally captured by electrostatic precipitators or other particle filtration equipment before the flue gases reach the chimneys of coal-fired power plants and together with bottom ash removed from the bottom of the furnace is in this case jointly known as coal ash. All fly ash includes substantial amounts of silicon dioxide (SiO2) (both amorphous and crystalline) and calcium oxide (CaO).

Fly ash particles are generally spherical in shape and range in size from 0.5 µm to 300 µm. The major consequence of the rapid cooling is that only few minerals will have time to crystallize and that mainly amorphous, quenched glass remains. It is a heterogeneous material. SiO2, Al2O3, Fe2O3 and occasionally CaO are the main chemical components present in fly ashes. The mineralogy of fly ashes is very diversed. Calcium aluminates identical to those found in Portland cement can be identified in Ca-rich fly ashes.

1) Class F Fly Ash:

The burning of harder, older anthracite and bituminous coal typically produces Class F fly ash. This fly ash is pozzolanic in nature, and contains less than 20% lime (CaO). Possessing pozzolanic properties, the glassy silica and alumina of Class F fly ash requires a cementing agent, such as Portland cement, quicklime, or hydrated lime, with the presence of water in order to react and produce cementitious compounds. Alternatively, the addition of a chemical activator such as sodium silicate (water glass) to a Class F ash can lead to the formation of a geopolymer.

Fig. 3: Fly Ash class F

2) Class C Fly Ash:

Fly ash produced from the burning of younger lignite or sub bituminous coal, in addition to having pozzolanic properties, also has some self-cementing properties. In the presence of water, Class C fly ash will harden and gain strength over time. Class C fly ash generally contains more than 20% lime (CaO). Unlike Class F, self-cementing Class C fly ash does not require an activator. Alkali and sulphate (SO4) contents are generally higher in Class C fly ashes.

Fig. 4: Fly Ash class C

E. Difference between Fly Ash And High Calcium Fly Ash:

Fly ash is a heterogeneous mixture of particles varying in shape, size, and chemical composition. The particles of a Class C fly ash may include carbon from unburnt coal, fire-polished sand, thin-walled hollow spheres and fragments from their fracture, magnetic iron containing spherical particles, glassy particles, etc. Fly ash is predominately composed of spherical particles which can be less than 1 µm to more than 1 mm. Mehta determined particle size distribution of a number of fly ashes. ASTM Class C fly ashes are relatively finer than ASTM Class F fly ashes. The nitrogen adsorption surface area of fly ash varies in the range of 300 to 500 m2/kg. Density of Class C fly ash normally varies between 2.4 to 69+2.8g/cm3.

In general, ASTM Class C fly ashes are characterized by higher CaO which called high calcium fly ash, somewhat higher MgO, and lower Al2O3 and SiO2 ASTM Class F fly ashes. Typically Class C fly ashes contain 20-50% SiO2, 15-20% Al2O3, 15-35% CaO, 5-15%

Fe_2O_3compared to, and up to 8% alkali. Major mineralogical components of fly ash are a silico-aluminate glass containing Fe_2O_3, CaO, and MgO, and contain certain other oxide minerals. The Class F fly ashes contain less than 5% of CaO, whereas Class C fly ashes (High calcium fly ash) normally show total CaO greater than 10%. Up to 43% CaO is found in some high calcium fly ashes from Barcelona, Spain. Crystalline mineral phases present in a Class C fly ash may include quartz, periclase, lime, calcium aluminate, calcium sulphate, alkali sulphates', in addition to glass which ranges between 60-90%. The presence of lime in Class C fly ashes can activate cementitious behaviour in the presence of water by the ash itself. Additionally, the calcium compounds and the alkali sulphates can participate in cementatious and pozzolanic reactions in concrete and Bitumen in the presence of moisture.

F. Materials And Methodology:

1) Materials Used In Bituminous Concrete Mix:

Aggregates For preparation of dense graded bituminous mixtures; the grading of aggregates was adopted as per MORTH (2013) for bituminous concrete given below (Table-1). Coarse aggregates consist of stone chips up to 4.75 mm IS sieve collected from a local source. Its specific gravity found in the laboratory was 2.75. Other physical properties of coarse aggregate are given below (Table-2).

Grading of aggregate of 20 mm, Table 2.2 sieve analysis

Sieve Size (mm)	Percentage passing by weight (Specified range)	Percentage passing by weight (Adopted)
26	100	100
19	90-100	95
9.5	80-60	70
4.75	35-65	50
2.36	20-50	35
0.30	3-20	12
0.075	2-8	5

Table 2: Physical properties of aggregates

Property	Testmethod	Testresult
Aggregate impact Value (%)	IS:2386 (Part-IV)	14
Aggregate crushing Value (%)	IS:2386 (Part-IV)	13
Los angles abrasion Value (%)	IS:2386 (Part-IV)	18
Flakiness index (%)	IS:2386 (Part-I)	19
Elongation index (%)	IS:2386 (Part-I)	22
Water absorption (%)	IS:2386 (Part-III)	0.1

The portion of aggregates passing 0.075mm is known as filler. Normally, cement is used as filler in bituminous mixes. In order to explore the use of high calcium fly-ash a very fine waste-product of thermal power station in bituminous paving mix, the same collected from local source has been used. For comparison point of view, cement collected from local sources has also been used in this study. The specific gravities of cement and high calcium fly ash used in this study were found to be 3.1 and 2.2 respectively.

Fig. 5: 20 mm Aggregates

G. Bitumen:

VG 30 grade bitumen has been used as bitumen for preparation of bituminous mixture. The important physical properties are given below (Table-3).

Property	Test method	Test result
Penetration value at 25ºC (0.1mm)	IS:1203-1978	68
Softening point (ºC)	IS:1205-1978	49
Specific gravity	IS:1202-1978	1.01
Absolute viscosity at 60°C (poise)	IS:73-1992	2505
Kinematic viscosity at 135°C	IS:73-1992	405

Table 4: Physical properties of VG 30 bitumen

1) Preparation of Mix Specimens:

The samples for bituminous concrete mixtures were prepared as per ASTM D1559 (1989) at different bitumen contents for each type of filler used. The mixtures with cement were considered to be control specimens. The optimum bitumen content for each type of filler in bituminous concrete mix was done as per the normal procedure.

III. TEST PROCEDURES AND RESULTS

A. Marshall Test:

Marshall Test is a simple and low cost standard laboratory test adopted all over the world for design and evaluation of bituminous mixtures. This test has been fundamentally used in this study to evaluate the different mixture at different bitumen contents and the parameters considered are stability, flow value, unit weight, air voids, voids in mineral aggregates, voids filled with bitumen. The optimum bitumen content was selected to have maximum stability maximum unit weight and median allowable limits for percentage air voids. The average of bitumen content corresponding to these two parameters is selected as optimum bitumen content.

1) Procedures:

The Marshall method was originally developed by Bruce Marshall of Mississippi State Highway Dept. and has been later developed adopted by the U.S. Crops of Engineers.

The method uses standard test specimens of 6.35 cm height and 10.16cm dia.The principal features of the method are a density-void analysis and stability-flow test of compacted specimen. The stability of the test specimen is the maximum load resistance in lbs or kg which it will develop at 60C.The flow value is the total movement or strain in units of 1/100 inch (0.254mm) occurring in the specimen between no load and maximum load during the test.

The test specimens are prepared with varying asphaltic cement content, with ½ % Increments, such that at least two values are above and two below the optimum. Usually 6 values of asphaltic cement content are selected for each, three specimens are needed. The specimens are prepared by heating the aggregates and binder and mixing them. The specimens are compacted by giving 50 blows on both top and bottom by standard hammer. The procedure is adequate for highway pavements designed for a tyre pressure of 0.7 MN/m2.For airfield pavements and heavily trafficked highway pavements designed for a tyre pressure of 1.4 MN/m2, 75 blows are given on each face. The Marshall testing machine is an electrically powered testing device designed to apply loads at a constant rate of strain of 5cm per minute and equipped with a calibrated proving ring to measure the load. The maximum load at failure is the stability value. A flow meter records the strain at the maximum load when failure occurs. The density and void analysis is then done.

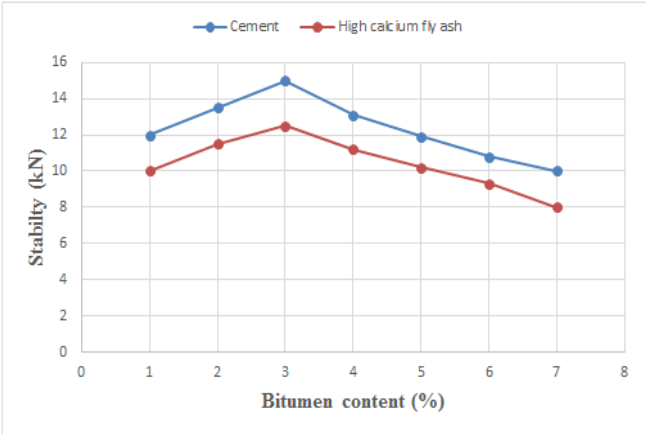
Fig. 6: Marshall Apparatus

All the Marshall criteria of the mixes at OBC are checked with respect to the same given in MORTH (2013). Although Marshall Method essentially empirical, it is useful in comparing mixtures under specific conditions.

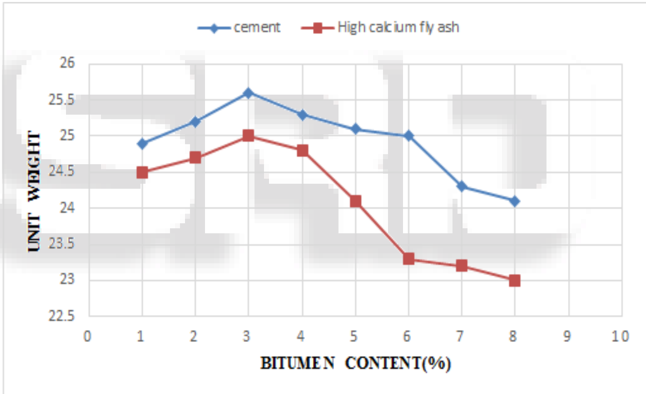
B. Results and Discussions:

1) Marshall Properties:

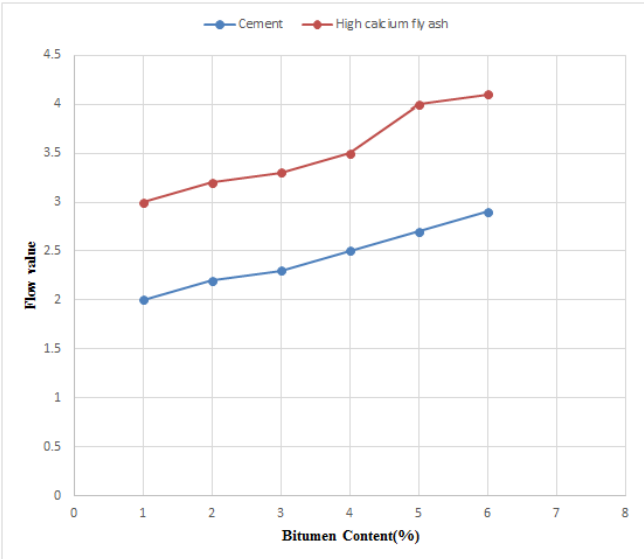
Two specimens for each combination were prepared and the average of these results has been reported. The results of Marshall Tests have been presented in Figures1 through6, in which the variations of Marshall Properties with respect to bitumen contents for all the two types of fillers considered in this study are shown. It is seen fromFigure-1and Figure-2that the Marshall stability and unit weight increase with bitumen content up to 5% after which these two parameters decrease. At any bitumen content the stability value and unit weight are highest for mixes with cement as filler followed by high calcium fly-ash. However, the variations are only marginal and the variation, particularly, stability is not significant to be considered.



Graph 1: Variation of Marshall Stability value with bitumen content for mixes with different fillers.

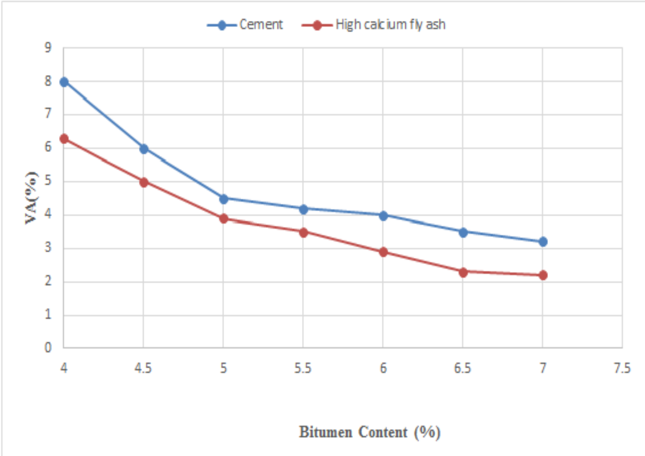


Graph 2: Variation of unit weight with bitumen content for Mixes with different fillers



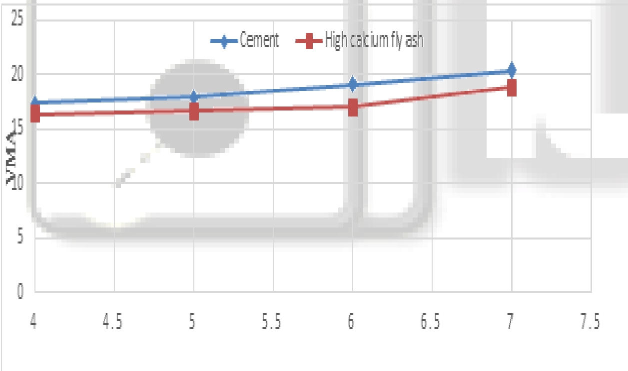
Graph 3: Variation of flow value with bitumen content For mixes with different fillers.

As shown in Figure-3 flow value increases with bitumen content. However, the flowvalue is lowest for mixes with cement as filler compared to High calcium fly ash. This is because cement makes the mix stiffer compared to the high calcium fly ash.

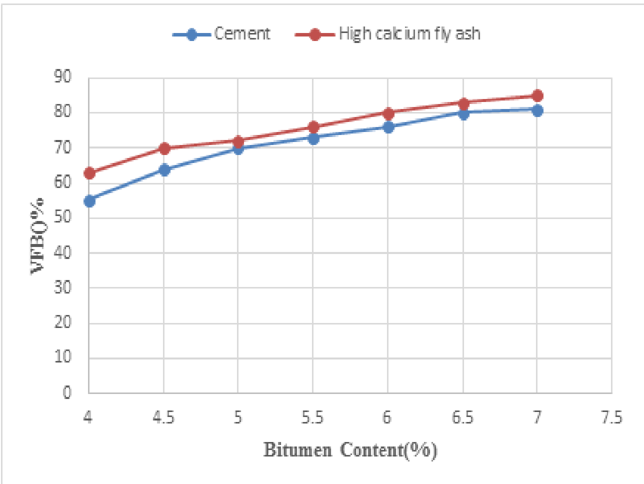


Graph 4: Variation of air voids with bitumen content for mixes with different fillers.

In similar manner Figure-3.5 shows that the air void decreases with increase in bitumen content. However it is to be highlighted that the high calcium fly ash causes maximum reduction of air voids compared to cement. This may be due to the fact that high calcium fly ash being too fine having highest surface area fills the voids more effectively.



Graph 5: Variation of voids in mineral aggregate with bitumen content for mixes with different fillers.



Graph 6: Variation of voids filled in bitumen with bitumen content for mixes with different fillers.

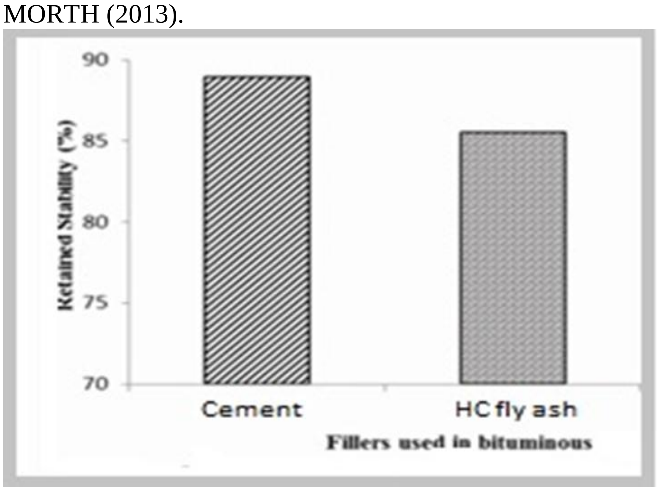
Generally OBC is appreciably affected by the mineral aggregates, bitumen and mix design. As presented in Table-4 the optimum bitumen content is also affected by different types of filler materials. High calcium fly-ash absorbs slightly higher bitumen than other fillers like cement so that it requires higher asphalt content. Bitumen content corresponds to maximum stability, maximum unit weight and the median of designed limits of percentage air voids in total mix. As per MORTH (2013), the OBC has been estimated on the basis of 4% of air voids in the mix. At OBC, the stability value, flow value, air voids, unit weight, VMA and VFB for mixes with three types of fillers considered in this study are also summarized (Table-4). It is to be noted that all the Marshall criteria as per MORTH (2013) are satisfied for all types of mixes covered under this study. The Marshall Stability value of mixes with high calcium fly ash is found only to be marginally smaller compared to cement mixture.

Filler type Parameter	**Cement**	**High calcium Fly ash**
OBC (%)	5	5.2
Stability(KN)	15	12.5
Flow value(mm)	2.3	3.3
Air voids (%)	4.5	3.9
Unit weight	25.90	24.70
VMA (%)	17	16
VFB (%)	73	76

Table 5: Marshall Characteristics of bituminous mixes with optimum bitumen content

2) Retained Stability of Bituminous Mixture:

The variation of retain stability for various types of mixes prepared at their OBCs considered in this study is presented in Figure-8. It has been observed that the mix prepared with high calcium fly ash exhibits lowest retained stability (RS) value compared to mixes with cement filler. This may be due to the fact that the high calcium fly ash used contains certain amount of lime which helps in anti- stripping property of bituminous mixes. It is to be noted that all mixes satisfy the minimum requirement of 75% specified by MORTH (2013).



Graph 7: Variation or retained stability for mixes with different types of fillers

IV. CONCLUSIONS

A bituminous paving mixture is a mixture of coarse aggregate, fine aggregate and bitumen mixed in suitable proportion to result strong and durable mix to withstand traffic load. In this paving mix, normally cement is used as filler material.

From the results of Marshall Tests and other performance tests conducted to explore the suitability of high calcium fly ash as filler in BC mixes, the following conclusions have been drawn:

- Maximum Marshall Stability and unit weight value are observed by cement followed by high calcium fly-ash filler. As usual, the results of the flow value show the reverse trends. However it has been observed that the variation is nominal and at optimum bitumen content the mixes satisfy all the Marshall criteria.
- The optimum bitumen content requirement in case of Cement is lower while for high calcium fly ash, the same is slightly higher. Considering the free and abundant availability of high calcium fly ash particularly at places near thermal power plants and where coarse aggregates are scarce, use of high calcium fly ash shall be cheaper compared to cement as filler.
- Hence it is generally concluded that high calcium fly ash can effectively be used as filler such as ordinary Portland cement. The former leads to high cost and latter may be costly at certain places where aggregates are scarce. Moreover, use of high calcium fly ash in paving mixes may give solution to high calcium fly ash utilisation and disposal problems and also give a means environment safe and clean.

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