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Study The Effect of Metakaolin Powder in Hot Mix Asphalt as Mineral Filler

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Abstract

Mineral fillers are crucial for bridging the spaces between the internal particles of the asphalt matrix. The purpose of this study is to investigate the mechanical properties of hot mix asphalt as well as the impact of utilising Metakaolin (MK) as a mineral filler. Coarse aggregate, fine aggregate, and filler are the main components of hot mix asphalt (HM). With or without modifiers, materials and asphalt binders. HMA components have passed testing to validate the suitability of the materials used in their production. Bitumen VG-40 was employed as the asphalt binder. On bitumen, tests for penetration, softening point, flash point, and ignition point were conducted. The planned control mixture had an optimal asphalt concentration of 5.2 percent. MK isn't in the control mix. MK Added replacement of a portion of the filler (used to be limestone powder). Various percentage of HMA filler like 25%, 50%,75% 100% replaced with MK. To assess the impact of MK's modification of the HMA, a comparison study was done. The inclusion of MK reveals important developments in Marshall Properties. The best amount of MK to add is 50%, and the best binder to use is 5.05%

Keywords: Metakaolin, Mineral Filler, Hot mix Asphalt, Marshal test, optimum binder Content

INTRODUCTION

Highways are critical to the emerging need for adequate transportation systems, as enormous amounts of money are spent on the structural design of highway pavement for national highway infrastructure. Increased overall traffic, poor-quality materials, and climatic conditions are the main causes of road damage. Permanent deformation of the road is the main cause of the road damage. Rutting a permanent deformation is one of the causes of road damage. The performance of pavement mainly depends on the materials used in highway construction. The materials used for road surfaces and load-bearing surfaces must be of high quality to improve road performance, which leads to increased highway costs. Researchers have therefore focused on finding new materials for the various layers of pavement structures that reduce construction costs and improve pavement performance.

For the bulk manufacture of bituminous mixtures, high-quality Additives are very expensive to modify asphalt pavement components. One solution to this issue can be obtained by considering the effects of natural mixtures Ingredients such as fillers [1]

The efficacy of hot-mix asphalt is largely determined by the properties of the aggregates used in the structure of the mix. The components of hot mix asphalt include coarse aggregate, fine aggregate, infill, and binder. Fillers are substances smaller than 75 microns that alter the performance of hot mix asphalt. Different types of filler materials are mainly used in the HMA as filler. Lime and cement were the conventional filler in

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HMA. The fillers used in the asphalt mixture are mainly affecting the mix design, specially the optimum binder content [2].

The properties of mineral fillers, especially those that pass through a 0.075 mm (#200) screen (commonly referred to as P200 material), have a significant impact on the performance of asphalt mixes concerning permanent deformation, fatigue cracking, and moisture sensitivity [2, 3].

The inclusion of mineral fillers in densely graded hot mix asphalt (HMA) paver mixes was initially implemented with the purpose of filling spaces within the aggregate skeleton and minimising voids within the mixture [4, 5]

Adding fillers to the mixture greatly improves adhesion and cohesion. The effect of filler addition is directly related to the filler properties and concentration in the bitumen-filler system. The addition of fillers helps reduce age hardening and improves low-temperature flow properties. The main function of mineral fillers is to strengthen the binder [6, 7].

MK has been used in the building sector as a partial substitute for cement since the 1960s, and interest in this substance has increased recently. Aluminum silicate hydrates linked to manganese (Mn), Iron (Fe), calcium (Ca), potassium (K), and sodium (Na) make up the chemical makeup of kaolin (Na). MK is created by heating kaolin for 90 minutes at a temperature between 650 and 800 °C, which results in an active pozzolanic content that can be used as a substitute or filler. MK significantly enhances the mechanical qualities of cement concrete. To generate high-strength concrete, some researchers substitute MK for cement. Modified concrete is stronger, more workable, more durable, and less air permeable than traditional concrete [8, 9].

Mk was added to replace HMA 20%, 40%, 60%, 80%, and 100% of filler. A comparative study was conducted to evaluate effect of HMA modification by MK. The Marshall Quotient (MQ) increases by 10.37%. Mixture modified at 40% MK. MK has a great influence on indirect tensile strength (ITS) [10, 7].

Metakaolin was added as a partial replacement for lime as filler and the mechanical properties of the marshal test were carried out and found that the marshal quotient increased by 10.37% and found that 40% replacement of line as filler is optimum and optimum binder content was 5.2% [11, 8]

The marshal stability, density, and flow increased as the Metakaolin was added up to 50% of the cement as a partial filler, then the value started decreasing at 75%, 100%. With increase in Metakaolin percentage air voids and VMA were decreased. The optimum replacement of Metakaolin was 50% and the optimum binder content was 5.2% [2, 10]

MATERIAL AND RESEARCH METHODOLOGY

Asphalt Mixture

The composition of asphalt mixture typically comprises of coarse aggregate, fine aggregate, filler material, and binder. The mixture contains about (4%–7%) of binder content. In this study, DBM grade 2 is designed. The properties of asphalt mix mostly depend on the size, quality, and mix design.

Coarse Aggregate

The coarse aggregates used in the research are crushed stone and brought from a locally available quarry (Dadri Haryana). The aggregate is commonly used in the construction of the highway in Haryana state. The course aggregate used for casting DBM GRADE-2 are of size between (19 mm–4.75 mm). The various tests are conducted on aggregate to investigate their physical properties as per [12]. The physical properties of aggregate were shown in Table 1

Table 1. Physical properties of coarse aggregate

S.N.	Property	Method	Result	Limit
1	AIV	IS-2386 PART-4	21.49	27% max
2	EI & FI	IS-2386 PART-1	31.97	35% max
3	Specific gravity	IS-2386 PART-3	2.605	-
4	App. Specific gravity	IS- 2386 PART-3	2.663	-
5	Water absorption	IS-2386 PART-3	0.83	-

Table 2. Physical properties of fine aggregate

S.N.	Property	Method	Result
2	Specific gravity	IS-2386 PART-3	2.605
3	App. Specific gravity	IS-2386 PART-3	2.663
4	Water absorption	IS-2386 PART-3	0.83

Table 3. Physical properties of bitumen VG-40.

S.N.	Property	Test method	Result	Limits
1	Penetration Value of Bitumen	IS: 1203	39.33	35 Min
2	Absolute Viscosity	IS: 1206 P2	3791	3200–4800 Poise
3	Kinematic Viscosity	IS: 1206 P3	563	400 Cst Min
4	Softening Point	IS: 1205	51.1	50°C Min
5	Ductility TFOT	IS: 1208	56	25 cm Min
6	Specific Gravity	IS: 1202	1.026	0.99 in

Fine Aggregate

The fine aggregate was obtained from the same source as the coarse aggregate. The fine aggregate is characterised by a particle size range of 4.75 mm to 0.075 mm. Various experiments were conducted on the fine aggregate in order to ascertain its physical characteristics.. The test outcomes were listed in the below Table 2.

Bitumen

Bitumen used in the study is grade of (40-50) penetration grade as per properties shown in Table 3. The bitumen is brought from the Panipat plant. Various tests penetration tests, softening tests, specific gravity, flash, and fire were carried out. Table 3 Describe physical properties of the bitumen.

Filler material

The filler material is used in asphalt to reduce the voids and to increase the density of the mix. The filler material should pass about 85% through the 0.075 mm sieve size. In this study, two types of filler material are used. One is the conventional filler (lime) and the other is Metakaolin used as a partial replacement for lime. Different tests were conducted on filler material as listed below. Physical and Chemical properties of Metakaolin is given in Tables 4 &5.

Grading of Aggregate

Grading of aggregate or particle size of aggregate influences the grade of the bituminous layer. Coarse aggregate and fine aggregate are separated through different IS sieves and proportion to a desired gradation for the bituminous mix. The grading of aggregate as specified in MORTH is used for DBM GRADE 2. The result of the combined gradation of aggregate is shown in the Table 6. The gradation is within specified limits as per the MORTH [12, 13] as shown in Figure 1.

Table 4. Physical properties of mineral filler (Metakaolin).

Property	Result
Specific gravity	2.9
% passing (0.075 mm)	94%

Table 5. Chemical properties of metakaolin

Chemical Composition	Result (%)
Loss on Ignition (L.O.I)	6.12
Silica (SiO_2)	51.29
Lime (CaO)	0.45
Magnesia (MgO)	0.23
Sulfuric Anhydride (SO_3)	0.14
Ferric Oxide (Fe_2O_3)	1.82
Alumina (Al^2O_3)	38.11
K_2O	0.43
Na_2O	0.11

Table 6. Result of aggregate gradation for job mix design

IS Sieve Size mm	Wt. Retained in (gms)	Cum. Retained in (gms)	Cum. Retained %	% of Passing	Mid value	Specified Limits As Per MORT&H Table No.500-10 Grading-2	
						Lower	*Upper*
37.50	0.00	0.0	0.00	100.00	100.00	100	100
26.50	0.0	0.0	0.00	100.00	95.00	90	100
19.00	5230.0	5230.0	18.68	81.32	83.00	71	95
13.2	3521.0	8751.0	31.25	68.75	68.00	56	80
4.75	5962.0	14713.0	52.55	47.45	46.00	38	54
2.36	4130.0	18843.0	67.30	32.70	35.00	28	42
0.300	5086.0	23929.0	85.46	14.54	14.00	7	21
0.075	2865.0	26794.0	95.69	4.31	5.00	2	8

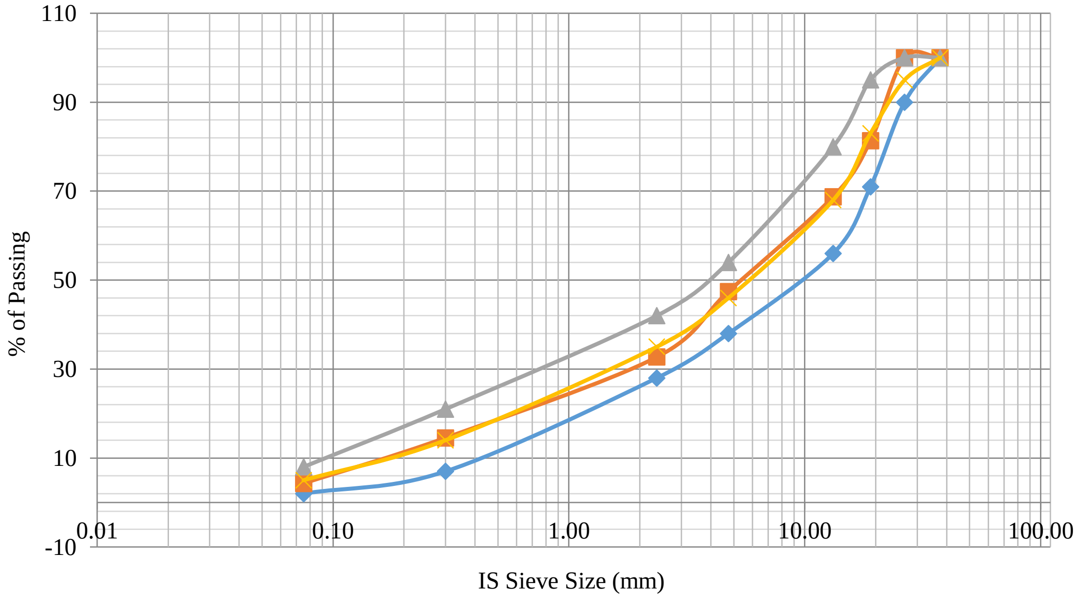

Figure 1. Job mix curves line [12].

Experimental Work

To Prepare the Marshall mould, the aggregate was graded in accordance with the specifications, and to determine the ideal bitumen concentration, the various bitumen contents 4%, 4.5%, 5%, 5.5%, and 6% mix for creating three moulds for each percentage replacement. Bitumen of various sizes and concentrations was combined according to their relative weights. Bitumen and aggregate are heated to temperatures between 160° and 170°C in a pan, and the combination is thoroughly mixed at a temperature between 160° and 170°C. After mixing, the mixture is transferred to a marshal mould, which has a base plate and collar extension and a diameter and height of 10 cm and 7.5 cm, respectively. This compacts the sample, and 75 blows are applied to it on both sides. Each compacted test specimen underwent stability and flow tests, void analysis, and unit weight estimation in line with the Marshall technique. The values of each individual specimen generated with a varied proportion of Metakaolin were then plotted. Figure 2 depicts the equipment used for the Marshall test.

For preparation of mould at different percentage of bitumen content when the Metakaolin is replaced as filler in different percentages (i.e. 0%, 25%, 50%, 75%, 100%) Marshall test were prepared to find out the optimum binder content. Three samples on each binder content (4%, 4.5%, 5%, 5.5%, 6%) were added and Marshall test was conducted to find out the various Marshall properties and to find out the optimum binder content at each replacement by Metakaolin. The optimum binder content is shown in Table 7.

Figure 2. Equipment of marshal test.

Table 7. Optimum binder at different mix proportions

Mix Metakaoline in %	0	25	50	75	50
Optimum binder in %	4.55	4.85	5.05	5.25	5.35

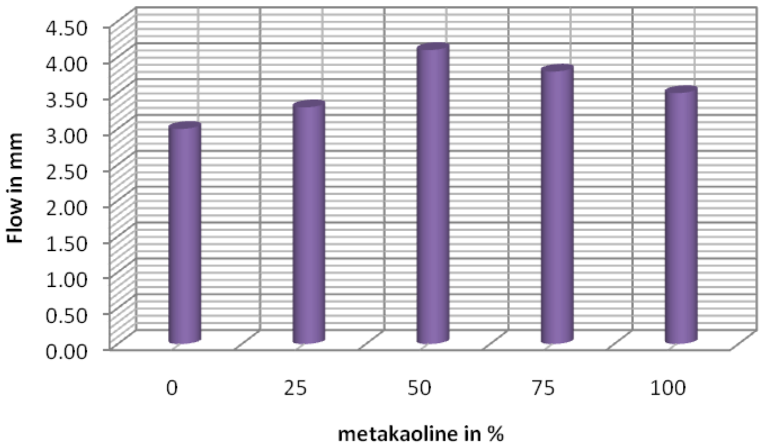

Figure 3. Variation in flow with % of metakaolin.

CONCLUSION

- Results show the increase in the percentage of Metakaolin (mixture with 100% Metakaolin) causes the increases in the optimum binder content and the reason is fines of Metakaolin.
- The air voids are decreasing up to 50% addition of Metakaolin and further addition of Metakaolin cause an increment in air voids.
- The result shows that there is a rise in the stability as the Metakaolin content is increased initially the rate of increase of strength was more than it start decreasing on further addition of Metakaolin as shown in Figure 3.
- The Marshall flow value increase as Metakaolin content increased up to 50%, then the value starts decreasing at 75 and 100 percent.
- The marshal density is increasing with increasing the Metakaolin content until it reaches up to its highest value at 50% of Metakaolin content further addition of Metakaolin cause a reduction in density.

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