EFFECT OF MECHANICAL PROPERTIES OF HOT MIX ASPHALT MIXTURE CONTAINING DIFFERENT PROPORTION OF FILLERS

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Abstract. This study investigates the effects of replacing conventional fillers in Hot Mix Asphalt (HMA) with alternative fillers such as Metakaolin (MK), Marble Slurry Powder (MSP), and White Shale Stone Powder (WSSP). Mar-shall Stability tests demonstrated significant improvements in mechanical performance, with stability increases of up to 30% and 61% at 25% and 50% filler replacement levels, respectively, particularly with Metakaolin. A combination of 50% conventional filler and 50% mixed fillers yielded the highest stability improvement of 62%. Other Marshall parameters, including density, Voids in Mineral Aggregate (VMA), and Voids Filled with Bitumen (VFB), showed minimal variation, indicating enhanced strength without compromising essential properties. Regression analysis confirmed the strong statistical significance of fillers as predictors ($p < 0.05$), achieving an R-squared of 98.76%, though multicollinearity among predictors was noted. The study maintained an optimal bitumen content of 5.7% across mixes, en-suring performance improvements were attributed to filler modifications. By incorporating industrial by-products like MSP and WSSP, this research high-lights a sustainable approach to pavement construction. The findings under-score the potential of Metakaolin and filler combinations to significantly en-hance asphalt performance, offering an effective and eco-friendly solution aligned with industry standards (MORT&H 2013).

Keywords: Hot Mix Asphalt, MSP, WSSP, Metakaolin, Stability, Marshall Test.

1. INTRODUCTION

The functional structures of asphalt concrete coatings are intricate and multifaceted, responding differently to various elements and their interactions. These factors include fillers, materials, environmental conditions, mixture kinds, characteristics, and so on [1]. Solid waste is presently one of the main issues in many nations. The need for landfill space is increased by ongoing growth in this kind of garbage, suggesting that this issue must be addressed. Due to its influence on our daily lives, environmental conservation and preservation are global challenges that societies must deal with [2]. Seven percent of CO2 emissions worldwide are produced by the cement sector. Scholars explore the possibilities for bringing this level down. Applying various supplemental materials may be the best way to handle this issue. As business has grown, an increasing number of wastes and byproducts have been produced, which has led to major issues with environmental contamination [3].

The increasing allowed axle weight and the ongoing rapid traffic growth call for improved roadway paving materials. The goal of highway research is to create pavements that are competent to support anticipated loads and are smooth, affordable, long-lasting, and safe. One of the ingredients in asphalt mixtures, filler, has a significant impact on the characteristics and behaviour of the mixtures, particularly in terms of binding and aggregate interlocking effects. Multiple studies have demonstrated that the characteristics of the mineral filler significantly im-pact the qualities of HMA mixes. Most fine kinds in HMA mixtures can be reused thanks to the implementation of environmental regulations and the approval of dust collection systems. The fines' impact on the characteristics of HMA mixtures varies, though, depending on factors such as gradation, particle shape, surface area, void content, mineral composition, and physicochemical characteristics [4].

2. OBJECTIVE

The study aims to evaluate how different proportions of fillers impact the Marshall Stability and flow characteristics of Hot Mix Asphalt (HMA). By replacing conventional fillers with varying percentages of alternative materials such as Metakaolin (MK), Marble Slurry Powder (MSP), and White Shale Stone Powder (WSSP), the research investigates changes in the mechanical properties of the asphalt mixtures. Marshall Stability, which measures the strength and load-bearing capacity, and flow values, indicating the deformation potential under load, are key parameters analysed. The findings help determine optimal filler combinations to enhance pavement performance and sustainability without compromising durability or compactness.

3. FILLER MATERIALS

The type and content of fillers can significantly affect the performance of asphalt mix.

Cement, Portland cement is a hydraulic cement made from ground clinker that is primarily composed of hydraulic calcium silicates with the inclusion of one or more forms of calcium sulphate as an inter-ground ingredient [5]. The typical chemical specifications for each kind are presented in ASTM C 150 and AASHTO M 85. Tricalcium silicate (C3S), dicalcium silicate (C2S), tricalcium aluminate (C3A), and tetra calcium alumino-ferrite (C4AF) are the ASTM markings for the phase compositions in Portland cement [6]. Cement is a hydraulic binder, primarily composed of calcium silicates and aluminates, that sets and hardens through a chemical reaction with water (hydration) to form a stone-like substance. It is produced by calcining limestone and clay in a kiln to form clinker, which is then ground into fine powder with additions of gypsum to control setting time. Concrete: microstructure, properties, and materials). Cement is a grey, fine-grained powder with high alkalinity. Its primary application is as a binding mate-rial in concrete, mortar, and grout, essential for construction of buildings, bridges, roads, and other infrastructure. Due to its binding properties, it also finds ap-plications in various industrial processes [7].

Metakaolin (MK), The pozzolanic substance known as metakaolin is produced by heating kaolin clay to temperatures between 600 and 800 degrees Celsius. The naturally occurring clay mineral undergoes a thermal treatment that turns it into a highly reactive, amorphous substance with special qualities that are advantageous to many industries, including ceramics and building. Metakaolin is used as a filler in hot mix asphalt to improve the mix's mechanical and durability properties. The density and stiffness of the asphalt are increased by its fine particles, enhancing its resistance to rutting and deformation. By strengthening the link between the aggregates and binder, metakaolin's pozzolanic action minimizes the possibility of stripping by increasing overall strength and decreasing water susceptibility. Metakaolin also increases resistance to oxidation and aging, prolonging the life of the pavement [8]. Its use in asphalt mixtures leads to improved performance under heavy loads and varying environmental conditions [9]. Fig. 1 shows metakaolin powder.

White Shale Stone Powder (WSSP), White shale stone powder is made by mining shale rock, which is then crushed and pulverized into small particles. Shale is removed from quarries and then the rocks are first crushed to minimize their size. After being crushed, these rocks are ground in mills to the appropriate powder consistency. The powder is frequently utilized in several industrial processes, including as the production of cement and as a product filler. The main reason white shale stone powder is included as a filler in hot mix asphalt is that it makes the mixture more durable and stable. Its fine particles reduce air gaps and increase the density of the asphalt by filling up the spaces left by larger aggregates. Better weight distribution and resilience to deformation under high traffic are the results of this. White shale stone powder also strengthens and extends the asphalt's general durability and resistance to moisture damage [10]. It is an important ingredient in the creation of durable, high-quality road surfaces because of these qualities. Fig. 2 shows white shale stone powder.

Marble Slurry Powder (MSP), Marble slurry powder is produced as a by-product during the cutting, shaping, and polishing of marble blocks. Water is used in the process to cool down the machinery, and the leftover marbles mix with the water to create a slurry. The fine marble particles in this slurry are mostly calcium carbonate. The solid substance that is still present is turned into marble powder once the water has been eliminated or dried. Because of its fine texture and binding qualities, this powder can then be utilized in a variety of industries,

Fig. 1 Metakaolin

Fig. 2 WSSP

Fig. 3 MSP

including construction, where it is employed as a filler in concrete and asphalt [11], [12]. Marble slurry powder is used as a filler in hot mix asphalt because of its capacity to boost mechanical qualities. It increases the asphalt's indirect tensile strength and Marshall Stability, enhancing its durability and resistance to deformation. By filling in the spaces left by bigger aggregates, the fine particles of marble slurry decrease air gaps and raise the mix's density. As a result, the road surface lasts longer because of improved weight distribution and resistance to moisture damage [13], [14]. Fig. 3 shows marble slurry powder.

Fig. 4 presents a graphical representation of the chemical compositions of the fillers, which closely resemble the chemical properties of cement. This similarity highlights the potential of fillers such as Metakaolin, Marble Slurry Powder, and White Shale Stone Powder to serve as sustainable substitutes, enhancing the mechanical performance of asphalt mixtures.

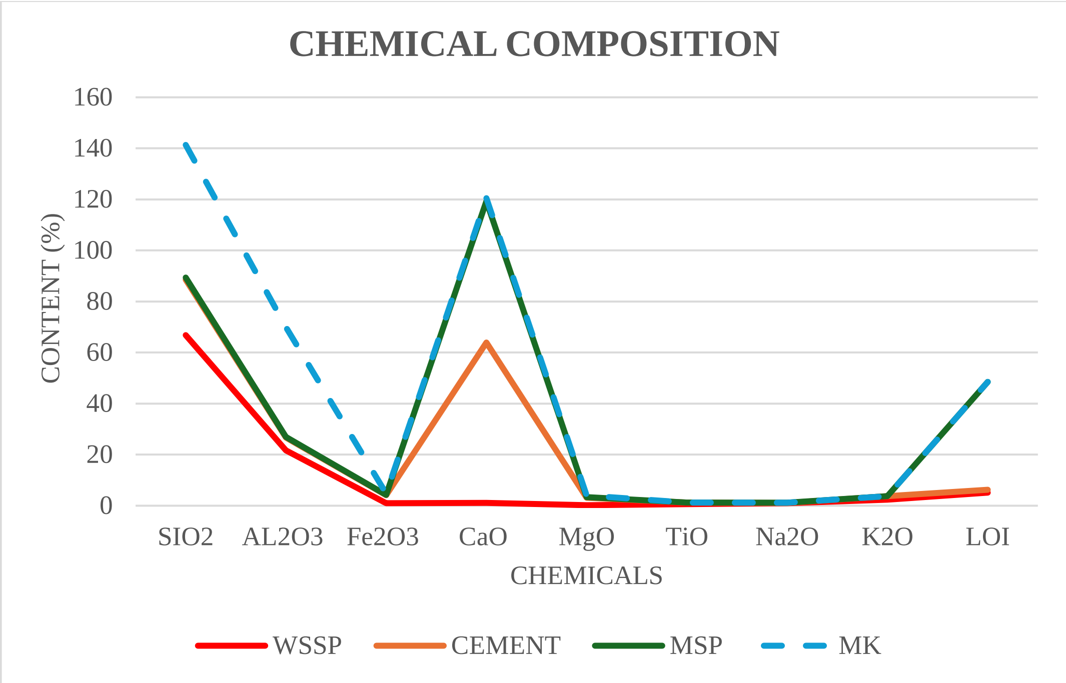

Fig. 4 Graph representing chemical composition

4. METHODOLOGY

The flowchart illustrates a systematic approach to evaluating and optimizing Hot Mix Asphalt (HMA) mixtures by incorporating different filler materials. The process begins with the selection of essential materials, including coarse and fine aggregates, VG-30 grade bitumen, and fillers such as cement (conventional filler) and alternative fillers like Metakaolin (MK), Marble Slurry Powder (MSP), and White Shale Stone Powder (WSSP). These materials undergo physical property tests to ensure their suitability for use in the asphalt mixture. Following this, the standard Marshall Mix Design is performed to determine the optimum bitumen content for the control mix. Fig. 5, shows methodology adopted during the study.

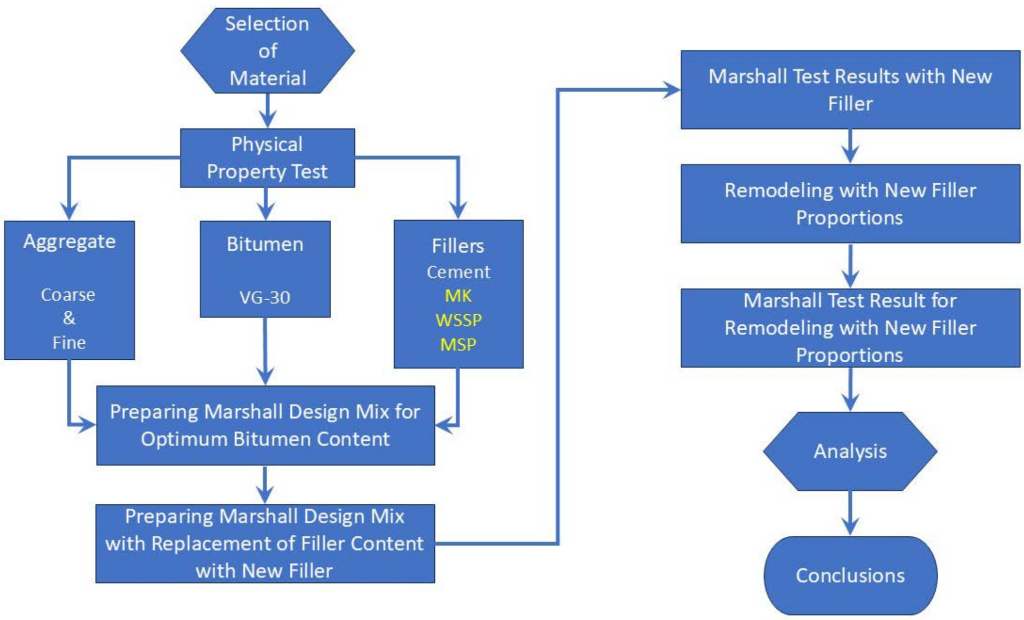

Fig 5 Methodology Flowchart

The next step involves replacing the conventional filler with alternative fillers at varying proportions to prepare modified mixes. These mixes are then subjected to Marshall Stability testing to evaluate their mechanical properties, including stability and flow values. Based on the test results, adjustments are made to the filler proportions, and the modified mixes are retested to achieve optimized performance. A thorough analysis of the results is conducted to compare the performance of conventional and modified mixes. The process concludes with the derivation of conclusions regarding the mechanical improvements and environmental benefits of using alternative fillers. This methodology ensures the development of sustainable, high-performance asphalt mixtures.

5. RESULTS AND ANALYSIS

The performance of Hot Mix Asphalt (HMA) mixtures under varying filler replacements evaluated through Marshall Mix tests at 75 compaction blows. Conventional mixes showed a stability of 1466 kg, with optimum bitumen content (OBC) at 5.7%, achieving 4% air voids, 16.07% Voids in Mineral Aggregate (VMA), 72.32% Voids Filled with Bitumen (VFB), and a flow value of 4 mm.

When replacing 25% of the conventional filler with Metakaolin (MK), stability increased by 30% to 1915 kg, while Marble Slurry Powder (MSP) and White Shale Stone Powder (WSSP) yielded stability enhancements of 22% and 23%, respectively. At 50% replacement, MK offered the highest improvement, with stability reaching 2367 kg (a 61% increase), compared to MSP (2156 kg, 47%) and WSSP (1946 kg, 32%). The final mix, combining 50% conventional filler with 16.67% each of MK, MSP, and WSSP, achieved a stability of 2381 kg, a 62% increase over the conventional mix. It also exhibited improved compactness with a density of 2.460 g/cc, 15.01% VMA, and 79.46% VFB, meeting the MORT&H specifications. Fig. 4.10 shows the stability of all the variations done in the mix, individually cement has stability of 1466 Kg, when we reduce cement and add 25% and 50% of MK we get stability of 1915 Kg and 2367 Kg respectively, which has a great hike in stability by adding such small amount of waste filler, similarly when add 25% and 50% of MSP we get stability of 1786 Kg and 2156 Kg respectively, also when we add 25% and 50% of WSSP we get stability of 1809 Kg and 1946 Kg respectively, last when we add all three different fillers in equal amount we get stability as 2381 Kg.

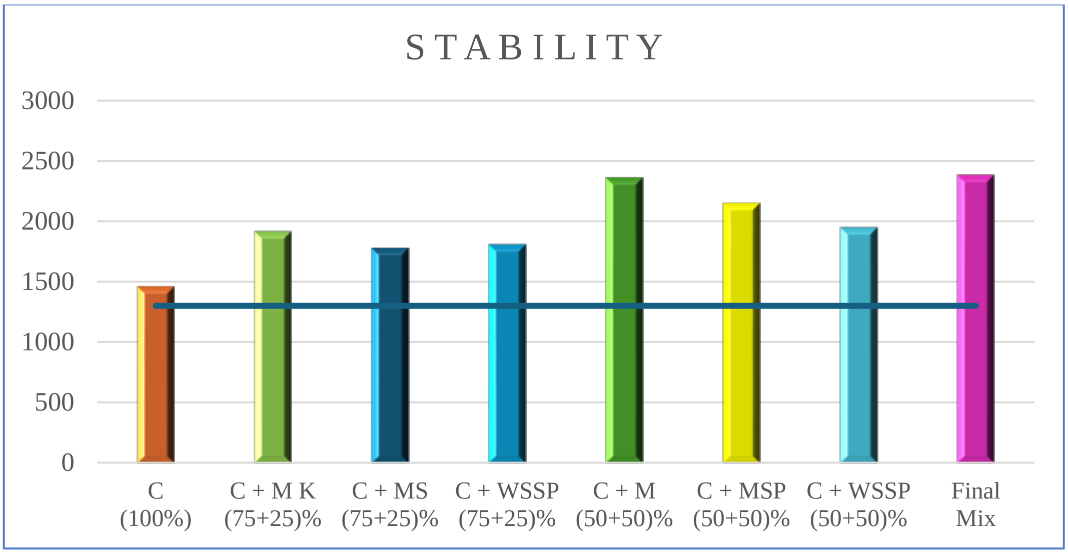

Fig. 6 Stability comparison among all variations

6. CONCLUSIONS AND FUTURE SCOPE

The conclusions of the study focus on the impact of replacing traditional mineral fillers in bituminous mixes with alternative materials like Metakaolin, Marble Slurry Powder, and White Shale Stone Powder. Tests revealed that replacing 25% of fillers improved Marshall stability by up to 30%, while a 50% replacement increased stability by 61%, with Metakaolin showing the highest effectiveness. A combination of fillers (50% conventional and 50% mixed) yielded a 62% stability improvement, highlighting the benefit of blending fillers. Other Marshall parameters, such as density and void characteristics, showed negligible changes, indicating that stability gains did not compromise these properties. Optimum bitumen content (5.7%) was maintained, affirming that performance enhancements were due to filler replacements. The study emphasizes the sustainability of using industrial by-products like Marble Slurry and White Shale Stone Powder in road construction, aligning with environmental goals. Future research could explore higher filler replacement levels and performance metrics like rutting and fatigue resistance.

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