Warm Mix Asphalt Incorporating Zeolite and Reclaimed Asphalt Pavement

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APPROVAL

It is hereby certified that the thesis entitled " **Warm Mix Asphalt Incorporating Zeolite and Reclaimed Asphalt Pavement** " submitted by Fatin Bin Ferdous and Md. Tanjim Islam Khan has been found as satisfactory and fulfilling the requirements for the Bachelor of Science Degree in Civil & Environmental Engineering.

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I hereby declare that the undergraduate research work reported in this thesis has been performed by me under the supervision of Dr. Nazmus Sakib and this work has not been submitted elsewhere for any purpose (except for publication).

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"In the name of Allah, Most Gracious, Most Merciful"

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Abstract

Warm Mix Asphalt (WMA) is a type of asphalt mixture produced at lower temperatures compared to traditional Hot Mix Asphalt (HMA). It incorporates either Organic or chemical additives as bitumen modifier.

Due to its advantages over traditional Hot Mix Asphalt (HMA) in terms of both the environment and economy, Warm Mix Asphalt (WMA) technology has attracted a lot of attention recently. In order to enhance WMA's sustainability and performance, this thesis looks into incorporating Zeolite and Reclaimed Asphalt Pavement (RAP) into the material. The study's main objectives are to assess this novel asphalt mix's mechanical qualities, potential environmental effects, and viability from an economic standpoint. The main objective of this study is to determine the Marshall stability and flow of WMA incorporating RAP and Zeolite. Zeolite has a unique porous structure that allows it to adsorb and hold water molecules, which may contribute to reducing the permeability of the asphalt mixture. Additionally, zeolite exhibits antioxidant properties and enables the production of Warm Mix Asphalt (WMA) at lower temperatures. Furthermore, it is readily available in the market at a lower price range.

Table of Contents

List of Tables

List of Figures

Chapter 1 Introduction

1.1 Background

Warm Mix Asphalt (WMA) is a type of asphalt that can be produced and laid at lower temperatures compared to traditional Hot Mix Asphalt (HMA). This is achieved by using additives, such as water, organic waxes, or chemical compounds, which reduce the viscosity of the asphalt binder, making it easier to mix and compact even at lower temperatures. Warm mix asphalt (WMA) has generated significant interest in the pavement sector due to its potential environmental and economic benefits. Recent research initiatives have focused on incorporating natural zeolite and reclaimed asphalt pavement (RAP) into WMA. Studies indicate that using RAP and natural zeolite as aggregates in WMA reduces emissions of volatile organic compounds (VOCs) and semi-volatile organic chemicals (SVOCs) compared to conventional hot mix asphalts (HMA) (Espinoza et al., 2020). Furthermore, life cycle assessments have compared the environmental impacts and performance of various asphalt mixtures, including WMA with naturally available zeolite and RAP (Martinez-Soto et al., 2023).

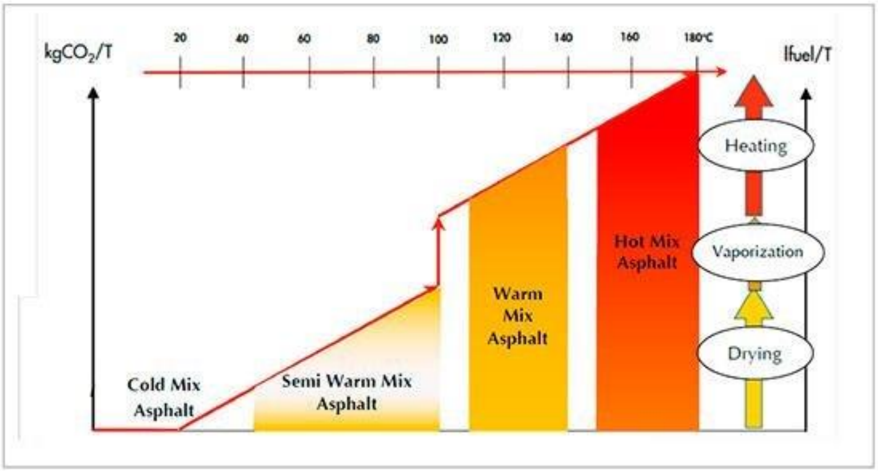

Figure 1: Change in temperature with different types of Asphalt

It has been established that using RAP with natural zeolite in WMA is a realistic procedure for creating environmentally sustainable pavement (Sanchez-Alonso et al. , 2020). Similarly, the incorporation of artificially synthesized zeolites to WMA as additives has been proved to have some advantages such as high resistance to irreversible deformation (Joni, Kad Hom and Mahood, 2019). Other works have also explored the use of WMA from zeolite by-products of petroleum refining, especially in the context of applying these materials sustainable methods of road construction (Sol-Sánchez et al. , 2019). Studies have also been performed regarding the WMA characteristics such as compaction and void distribution with reference to the zeolite additives, and therefore it is very important to understand the effects at the binder level (Ren et al. , 2019).

Furthermore, research has been done to assess how warm mix additives, such as synthetic zeolites, affect characteristics of SBS-modified asphalt which result in low temperature cracking, rutting and fatigue cracking of the asphalt pavement (Zhang & Li, 2019). Adding RAP into asphalt mixtures is a practice that allows for effective utilization of resources thus cutting down on material and disposal costs as well as promoting sustainability (Nasir, 2024). Additionally, research has focused on mechanical properties and durability of RAP modified bituminous mixes indicating improved stability, tensile strength and stripping resistance when compared with non-RAP mixes (Fattah, 2023). It is important to note that this study demonstrates that an environmentally sustainable road construction can be achieved while maintaining performance levels.

1.2 WMA Technologies

1.2.1 Usage of Water

Using this method, a small amount water boils to 1.673 times its volume at atmospheric pressure. When this happens, additional asphalt binder is added to the mix that in turn helps to coat the aggregate and lowers the apparent viscosity of mixture.

1.2.2 Usage of Organic Additives

WMA, with organic additives, requires reduced temperatures of manufacture to save energy and reduce emissions. More RAP content makes WMA more durable and sustainable compared to traditional hot mix asphalt. Improved workability, resistance to moisture, and ease of application are some of the added benefits that allow WMA to find a wider application base than standard hot mix asphalt.

1.2.3 Usage of Chemical Additives

Warm mix asphalt (WMA) can be mixed and placed at lower temperature, which is obtained by the addition of chemical additives to reduce viscosity in the binder. As a result, the production savings on energy and emissions are up across-the-board. WMA, containing chemical additives that make it workable for compaction and thicker lifts than HMA (permitting greater use of RAP), outperforms HMA in both service life durability and moisture susceptibility by making the product more cost effective as well as environmentally friendly.

1.3 WMA's advantages Compared to HMA

There are some advantages when comparing warm mix asphalt (WMA) to hot mix asphalt (HMA). However, there are some favorable conditions when using warm mix asphalt in relation to hot mix asphalt. The main advantage is the customary range of 20–40°C reduction in pavement and manufacturing temperatures. For this reason of saving energy and minimizing emissions of greenhouse gases due to this lesser requirement of temperature, WMA is more sustainable. The reduction of temperatures also contributes to the safety of workers for example in building construction companies where workers will be less often exposed to contaminants and high temperatures. Moreover, the method of doing asphalt work at a time when the weather is extremely cold can also possibly prolong the paving season.

Some other benefits of WMA include an enhancement of compaction as well as the workability. WMA additives improve on the capability of the asphalt mixture to be compacted to a higher density and hardness. WMA also permits inclusion of increased quantities of reclaimed asphalt pavement (RAP) percentages which in turn increases sustainability and recycling within the construction industry. Also, the transport of WMA over longer distances can be done without experiencing a very high level of temperature and this offers more flexibility in terms of program and project sequences. In conclusion, WMA not only strengthens pavement, enhances the quality of the pavement but also enhances safety and the conservation of the environment.

1.4 Reclaimed Asphalt Pavement (RAP)

The utilization of reclaimed or recycled asphalt pavement is for the production of warm mix asphalt (WMA) and several other new asphalt mixtures (RAP). It has several advantages, and as it is sustainable. It helps to preserve natural resources such as aggregates and asphalt as they are not therefore required in such huge quantities as before, not to mention cutting down the flow of asphalt wastes to the landfill. This aspect alone is sufficient to establish that owing to lowered temperatures of production as a result of RAP and WMA integration, energy utilization and the consequent GHG emissions relating to production by the company are considerably reduced.

WMA offers performance advantages to RAP. Recycling materials also cuts costs associated with producing asphalt since recycled products often more cost effective than virgin materials. Additionally the aged binder, in RAP can sometimes be processed to a consistency and combined with binder enhancing the overall strength and durability of pavements.

The WMA binders ensure that the re-cycled material that remains in line with the fresh mix attains better compaction, hence leading to a more homogenous pavement structure, thus permitting higher percents of RAP incorporation. And WMA can take advantage of the financial and performance advantages that RAP has too. Generally, re-cycled materials are cheaper and less expensive to use than new virgin ones; the cost of buying fresh asphalt material is reduced. Moreover, asphalt binder in RAP is sometimes stiffened by aging for durability and longevity and may raise the strength of the pavement as a whole if milled and mixed only properly to the reinforcing effect with fresh binder. This is where the warm-mix additives, in reshaping the RAP and RELA, actually allow proper blending between used material and that of fresher mix, resulting in better compaction and an overall, more uniform structure of pavement.

1.5 Zeolite

When heated, the zeolite additive in warm mix asphalt (WMA) results in water that is released as steam, thereby enhancing the properties of the mixture. This steam makes the asphalt binder foam, which significantly reduces its viscosity. With a lower viscosity, asphalt can be mixed and applied at temperatures 20-40°C lower than those required by conventional hot mix asphalt (HMA). Lowering this temperature leads to substantial energy savings and less greenhouse gas emissions during production.

The zeolite’s foaming effect enhances workability of the asphalt mix; thus making it easier to handle, spread and compact. Better workability means more efficient compaction of the asphalt resulting in optimum density and longer lasting and resilient pavements. Also, this feature allows for extended periods when builders can use this material as it slows down how fast the mixture cools before it is compacted properly.

1.6 Scope of Study

In this study, zeolite-treated warm mix asphalt (WMA) and reclaimed asphalt pavement (RAP) are examined in order to determine the potential benefits and performance attributes of using them. This research aims to find out if by adding these elements, will make asphalt pavements last longer and make them more environmentally sustainable. The study’s aim is to carry out a comprehensive evaluation of mechanical properties, compaction characteristics, and long-term performance of the resultant asphalt mixture by investigating how zeolite affects the temperature of WMA during production as well as the workability thereof while including RAP for recycling and conservation purposes. As such, this examination will help come up with more efficient paving solutions that take into consideration modern trends towards sustainable infrastructure development.

1.7 Objectives

1. To look for the differences between HMA and WMA

2. To establish useful concentration of Zeolite and RAP.

3. Run the Marshall Stability and Flow test for stability and flow respectively.

4. Cut down on dependence on natural resources.
5. Lessen the energy usage and greenhouse gas emission.

1.8 Organization of Thesis

Chapter 2: Literature Review- This chapter looks at the prior research done on related topics and presents guidelines for its use.

Chapter 3: Methodology – The chapter reveals how the methodology was like from scratch.

Chapter 4: Findings and Discussion - This chapter highlights findings obtained from the experiment as well as data that were collected.

Chapter 5: Conclusion - Finally, this chapter summarizes what has been achieved and how effective it has been.

Chapter 2 Literature Review

2.1 Introduction

Efforts have been aimed at enhancing the sustainability of pavements by incorporating natural zeolite and reclaimed asphalt pavement (RAP) in WMA (Espinoza et al., 2020). It can be exclusively said that incorporating zeolites into WMA increases both rutting and mixture modulus properties (Sánchez-Alonso et al., 2018) since most of the previous studies emphasized on enhancement in paving characteristic by utilizing using equal additive. Also, the applicability of WMA additives such as Sasobit H8 or Advera zeolite at lower temperatures to improve RAP workability and mechanical properties has been investigated (Tao & Mallick, 2009). LCA studies were performed for environmental evaluation of asphalt mixtures such as hot mix asphalt (HMA) and WMA with natural zeolite, RAP. This, together with tests confirming that WMA can achieve comparable performance to HMA in emissions and energy consumption (Martinez-Soto et al.2023). The utilization of Zeolites in WMA also reduced the mixing temperatures and helped to minimize Asphalt Binder viscosity, which further states that addition with zeolite is among one sustainable pavement solutions (Hilal & Fattah, 2022). In asphalt mixtures (Sanchez- Alonso et al., 2020), molecular bond energy, morphology [72] and functional groups are also affected by these warm additive which directly affects the durability and performance of material in explaining host series research work. Furthermore, the application of medicated zeolites as warm mix added substances seemingly has indicated improvement on irreversible distortion decline and adapted pavement implement (Wang et al., 2022).

Shariq Zaumanis & Rafiqul Tarefder in 2014 reviewed a number of methods for increasing the proportion of RAP that can be employed into asphalt mixes, offering an overview on current practices and issues with higher fractions than are currently typically added to virgin aggregate stockpiles. This can be done using the life cycle assessment of natural zeolite based WMA incorporating RAP and then key environmental consequences, as well as sustainability aspects of various asphalt mixtures designed for similar performance (Martinez-Soto et al., 2023). These studies add to the body of knowledge in the environmental impact and sustainability implications associated with RAP inclusion in WMA.

2.2 Purpose of Study

2.2.1 Environmental Benefits:

Most studies on warm mix asphalt incorporating zeolite and reclaimed asphalt pavement are relevant to pavement construction sustainability. The use of natural zeolite and reclaimed asphalt pavement (RAP) to improve properties of warm mix asphalt (WMA) is reported by researchers in an effort at improving the environmental friendliness of asphalt production and utilization. Some of the ways that have been found to minimize the formulating WMA environmentally include the use of a zeolite additive to lower CO2 emissions and fuel consumption during the production (Belc et al. , 2021). The introduction of WMA technology, facilitated by additives like zeolite and RAP, enables a significant reduction in manufacturing temperatures, leading to energy savings and environmental benefits (Belc et al., 2021).

2.2.2 Regulatory Compliance and Cost Efficiency:

Moreover, with the integration of RAP into the WMA, the need for new aggregates is eliminated while at the same time it supports the concept of reuse rather than the production of new materials. (Lu and Saleh, 2016). Research has shown that the use of the WMA technology reduces the temperature at which asphalt mixtures are produced compared to that of HMA and hence conserves energy and allow for a possible incorporation of increased RAP content into the mix (Sol-Sánchez et al. , 2019). Also, the use of the by-products of zeolite in WMA is a good example of recycling industrial waste materials in road construction (Sol-Sánchez et al. , 2019). Research has therefore sought to establish the interaction between zeolite and RAP in WMA formulations to produce cost effective, environment friendly and long-lasting asphalt pavements for use in future infrastructural development projects.

2.2.3 Performance Improvement:

It is documented that incorporating zeolite and RAP in WMA enhance pavement performance and have some environmental benefits including, low emissions of volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs) and the improvement of workability of asphalt mixtures (Espinoza et al. , 2020). The incorporation of zeolite and RAP in WMA formulations is a good line of approach worthy of being explored to the full with regard to its impact on sustainable and high performing asphalt pavements. However, the present study of warm mix asphalt containing zeolite and reclaimed asphalt pavement is helpful in the development of the warm mix asphalt and the construction industry. Thus, through life cycle assessment and laboratory investigations on various forms of asphalt mix like HMA (control sample), WMA with natural zeolite and WMA added with RAP, the authors endeavour to understand the environmental footprint contour and performance potential of these composites (Martinez-Soto et al. , 2023). Incorporation of the WMA has been acknowledged to improve the compaction of the asphalt mixtures without any effects on the resilient modulus or making the mixtures more vulnerable to rutting; this means that there are possibilities of improving the pavement performance (Sánchez-Alonso et al. , 2018). Moreover, it has been also reported that WMA with zeolite as the additives had also synergistic interaction with the other material such as polymer modified asphalt binders and which improved the adhesion characteristic of asphalt mixtures in general (Handayani et al. , 2015). In view of the findings of this research, there is need to search for new materials and technologies to help improve on the production of sustainable and quality asphalt pavements. Moreover, incorporation of zeolite and reclaimed asphalt pavement (RAP) into warm mix asphalt (WMA) also eliminates individual aspects of the crucial problems encountered in asphalt production and pavement construction industry. With reference to the gradation design, parameter determination, and mechanical behaviour of WMA mixtures with and without the use of zeolite and RAP, researchers strive to enhance and increase the efficiency of asphalt pavements (Xiang et al. , 2022). Research has shown that WMA that uses zeolite and RAP for HMA has better workability, lower fume emissions and better pavements than HMA. (Espinoza et al. , 2020).

In conclusion, the research carried out on warm mix asphalt using zeolite and reclaimed asphalt pavement is a noble exercise towards the advancement of sustainable approach in asphalt technology and construction of pavements. To enhance the mechanized properties of pavement, reduce environmental impacts, and promote circular economy principles in asphalt industry, researchers employ natural zeolite and recycled materials, such as RAP in WMA formulations Scientists are still working on the plans of general application of WMA technology with the use of zeolite and RAP additives through the results of life cycle assessments as well as lab analyses and performance tests. This technology is a convenient solution for future construction projects, which are more difficult to be implemented.

2.3 Types of Warm Mix Asphalt Technologies:

(Tong et al. ,2022) examined the performance alteration of cold recycled asphalt material by applying Sasobit warm mix and reported the micro characteristics of warm mixed recycled asphalt varying with RAP content. Production methods of warm-mix-asphalt mixture were highlighted by (Xiang et al. ,2022) and incorporated Aspha-min. In their recent study, (Woszuk & Franus. ,2017) summarised the impacts of adding zeolite to the properties of asphalt and mix asphalt that are directly connected with specific materials such as Aspha-min. (Wang et al. ,2018) described the adhesion between asphalt and rubber and the influence of warm mix additives on the mechanical characteristic and its wearing course durability of warm mix rubberised asphalt. The aspect of the importance of WMA was also highlighted by (Xie et al. ,2014) in which the author highlighted lower energy use, lower CO2 emission and better working conditions when using Evotherm WMA technology, in line with the aim of discussing the environmental advantages of Evotherm WMA. (Valdés et al. ,2011) have also carried out an experimental comparative study on the mechanical characteristics of bituminous mixtures containing high proportions of RAP which is in a straight line with the utilization of RAP in Evotherm Warm. Further, (Dinter et al. ,2021) still gave ideas about the automation of systematic literature reviews, which could be helpful for the macrolearning in searching comprehensive literature on the topic. Akentuna et al. study focused on the improvement of in-place field density using Evotherm WMA additive to the performance characteristics of Evotherm Warm Mix Asphalt. (Rezapour & Wulff ,2019) assessed the rut performance of in situ warm mix asphalt overlays utilising Evotherm 3G and presented details on the practice and performance of the Evotherm innovation. Further, (Mantalovas & Mino ,2019) were seminal to contemplate the sustainability of the reclaimed asphalt as a resource for managing the road pavement and such is handy to the use of Reclaimed Asphalt Pavement in Evotherm Warm Mix Asphalt.

2.4 WMA using Zeolite

There are various works that have been done in connection to the utilization of zeolite materials in warm mix asphalt (WMA) technologies. In Woszuk & Franus, 2017 the authors gave the outcomes of the studies on the effects of zeolite addition to the properties of asphalt and mix asphalt and the environmental, economic and technological advantages. Further, in WMA technology, Woszuk et al. (2019) presented how zeolite materials can be used as asphalt foaming agent by partially substituting the filler used in WMA. In addition, Belc et al., (2021) concentration was on the LCA of hot mix asphalt and WMA made from locally available materials and warm mix additives such as synthetic zeolite. Furthermore, Li et al. (2020) examined the workability of preparing the WMA mixture by incorporate of recycled asphalt pavement (RAP) based on natural zeolite which has a sign of sustainable pavement construction. Further, the work of Ren et al., (2019) looked at the void distribution within the zeolite WMA mixture, regarding the overall potential of the natural zeolite in reducing the mixing temperature, but at the same time influence the water stability of the asphalt mixture. In addition, Sánchez-Alonso et al. , 2018 identified that using of zeolites enhanced the compaction of the mixture while did not enhance the rutting potential of asphalt mixtures. Poor results have been noted in the inclusion of zeolite in WMA showing improvement in the properties of asphalt, reduction of mix temperature and sustainability of construction of pavements. Based on the case of applying zeolite as an element of the WMA technology, it might be claimed that the application of such an additive has environmental and economic advantages in the framework of asphalt industry.

2.5 Stability of WMA-RAP

Compared to control mix and cold in-place recycled asphalt, Naser et al. (2019) proved synthesis and characterization of improved recovered asphalt with an addition of nano emulsion acrylate terpolymer that enhance the stability of the material. They outcomes of this research reveal that nano emulsion terpolymer may improve RAP stability in WMA and represent a creative way to enhance RAP stability.

However, (Xie et al ,2021) realised that use of recycled materials in warm-mix reclaimed asphalt mixes may increase the stability issues of the aggregate skeleton structure. This underlines the importance of dealing with stability problems connected with the utilisation of RAP in WMA.

2.6 Performance Evaluation of WMA using RAP

Asphalt mixtures with various zeolites in their formulation were used by De Visscher et al (2010) in their evaluation of mechanical properties of the material. The results showed that when the compaction temperature was below 120 C, the incorporation of zeolites deteriorated the compatibility as well as the water sensitivity; however, the reduction of the manufacture temperature to 120° C did not prove to have a detrimental effect of the rutting stiffness against the reference mix, manufactured at 150° C Three compaction temperatures were used in designing the mixtures: 145°, 130° and 50% with m for the natural rubber compound and 5% w/m for the synthetic one. Wu and Li (2017) investigated the curing time of WMA produced with AdveraWMA, as well as dynamic modulus, rutting, moisture damage and fatigue properties. The analysis, which was done on the performance of the WMA properties revealed that the curing time of WMA properties enhanced the WMA properties probably due to the elimination of water incorporated in the asphalt mixture while the hot asphalt mixture did not change with the curing time of the evaluation.

2.7 Moisture Susceptibility of WMA-RAP:

Zhao et al. (2012) studied the rutting resistance, moisture sensitivity and fatigue properties of WMA with high RAP content and found that the addition of RAP improve these properties. Poor workability was also identified whereby they established that the moisture susceptibility of WMA pavements can be greater than that of hot mix asphalt due to the use of softer binder, water bearing additives and water based foaming processes. Georgiou & Loizos, 2021 reported that overlays with hot mix recycled asphalt have comparable or higher characteristics as hot mix asphalt including; moisture susceptibility, dynamic modulus, permanent deformation, fracture toughness and surface texture.

2.8 Benefits of WMA-RAP:

Gungat and Hamzah (2015) noted on environmental gained from the incorporation of RAP in pavement layers such as emissions to atmosphere, energy and water, lifecycle cost and hazardous waste The paper by Woszuk and Franus (2017) discussed the impact of zeolite on properties of asphalt and mix asphalt and also environmental, economical and technological advantages of WMA technology. For environmental aspects, Georgiou & Loizos (2021) analyzed the savings of industrial by products, recycled materials and additives of WMA in wearing course mixtures of asphalt pavement construction. With respect to performance, RTC of WMA mixtures containing High percentage of RAP by Zhao et al., 2012, through controlling performance tests rutting resistance, moisture susceptibility and fatigue resistance, showed the performance potential of the WMA technology Furthermore, Wasiuddin et al., (2007) pointed that the warm mix additives were also found to enhance the stability and resistance against deformation of asphalt mix at operations temperatures and high traffic which enable the use of WMA at higher ambient temperatures, Mallick et al. (2008) studied the possibility of using a warm mix asphalt additive to successfully recycle HMA with a higher percentage of RAP with less heat, hinting great possibility of WMA technology in incorporate higher percentage of RAP material in asphalt mixtures.

2.9 Benefits of HMA-RAP

Gungat and Hamzah have supported the view of applying RAP in HMA stating that the process is cheap than paying more costs in the construction and maintenance of the asphalt pavements. Abd Ali et al. (2024) documented that the use of this strategy help to save natural resources as well as reduce pollution in the environment. Zhang et al. (2023), revealed that through the use of RAP in HMA reduction in pavement can make a contribution to the lowering of carbon emission and energy use.

2.10 Challenges of WMA-RAP

● Mixture design complexity: Qian et al. (2015) noted in their study that while designing WMA mixtures, consideration must be given to the choice of WMA technology and its compatibility with other mix components.

● Performance variability: The National Center for Asphalt Technology (2018) states that, among other things, WMA technology and RAP content affect how well WMA performs in comparison to HMA.

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● Limited long-term data: Long-term performance data on WMA is still limited according to Asphalt Institute (2017), making it difficult to fully assess its durability or sustainability over extended periods of time.periods.

2.11 Research Gaps and Trends

2.11.1 Interaction Between Materials and Combined Effects:

Further studies are required to establish the effects of blending WMA with RAP and other enhancers or adjusters or modifiers (such as recycled plastics or warm mix additives). Despite the fact that all the technical and performance characteristics of WMA and RAP have been thoroughly investigated in various earlier works, to date, studies on the combined effect of utilizing both zeolite and RAP to improve the properties of asphalt mixes are scarce. Vidal et al. Boarie (2024) established the need for researchers to search for new approaches to the utilisation of asphalt binder samples incorporating WMA and RAP. Also, Valdés-Vidal et al. (2018) also stressed on the concept of sustainable pavements construction by assessing the WMA using natural zeolite and RAP. Hence, these studies call for the need to examine the interaction of zeolite and RAP within WMA to improve sustainable performance of pavements. This is in consonance with the general objective of having sustainable pavements to implement and with minimized environmental degradation The concepts of the study by Nihad & Sarsam (2020) on the differences in the properties of HMA and WMA asphalt concrete provide evidence that WMA, especially when using RAP and zeolite has unique features with regards to production and compaction, especially when using lower temperatures, thus helping the conservation of energy and reduction of environmental impacts. Additional research on the interaction of zeolite and RAP in WMA can be further supported by works like (Obaid et al. , 2022) wherein the effects of RAP together with waste polyethylene in asphalt mixtures were analyzed; this underpins larger interest in modifying the properties of asphalt to new extents.

2.11.2 Life Cycle and Performance Analysis:

As mentioned before, it is believed that both WMA and RAP are not detrimental to the environment, nonetheless, further comprehensive research over impacts of both techniques inclusive of any swap over is deemed essential. Martinez-Soto et al. (2023) include evaluating the utilization of resources, energy consumption, and emissions during their total lifecycle. As a control sample, the study used the conventional hot mix asphalt to compare it with warm mix asphalt containing zeolite and recycled asphalt pavement and other warm mix asphalt with natural mineral additives. This assessment approach gives a broad perspective of the consequences of integrating zeolite and RAP in WMA on the environment as well as sustainability. In addition, Rahman et al. (2021) also stated that technology such as WMA with RAP is crucial for constructing environmentally sustainable asphalt pavements in the future from which the shift in the direction of sustainability was noted. Based on volumetrics of the mix design, as well as the propensity for cracking, Rahman et al. (2021) pointed to the possible advantages of the flexibly applied RAP in WMA, but at the same time stressed on the fact that more thorough investigations are needed into this matter.

2.11.3 Performance Standards:

There is a need for a unified set of guidelines and standards in the application of WMA with RAP. Bohn's (2023) study on the properties of fresh Warm Mix Asphalt (WMA) mixtures modified with Reclaimed Asphalt Pavement (RAP) in varying proportions clearly demonstrates the global applicability of WMA and RAP solutions, indicating a greater need for research to obtain the best of the existing solutions. This study's examination of the rheological behavior of WMA-RAP asphalt binders helped illuminate the mechanical features of these mixtures while suggesting that more thorough investigations and analysis of the synergistic impacts of zeolite, RAP, and WMA additives should be done.

Thus, there remains potential to improve high-performance and environmentally friendly pavement construction methods if the knowledge gap regarding warm mix asphalt incorporating zeolite and reclaimed asphalt pavement is filled. Overall, the findings of multiple studies highlighting the mechanical, environmental, and performance qualities of WMA with zeolite and RAP indicate that more research is being done in this area to optimise asphalt mixtures to meet the needs of contemporary infrastructure construction projects using WMA more successfully while reducing adverse environmental effects and enhancing sustainability.

Chapter 3 Methodology

3.1 Materials and Their Properties

3.1.1 Materials Used

In our research, we utilized several key materials to prepare the asphalt mixture. Coarse aggregates, specifically those with a size of 20 mm and smaller, were selected to provide the necessary strength and stability to the mixture. Fine aggregates, ranging from 0 to 5 mm in size, were also used to fill the voids between the coarse aggregates and ensure a dense, well-graded mixture.

Crushed Stone Dust (CSD) was incorporated as a filler material to further enhance the density and stability of the asphalt. Reclaimed Asphalt Pavement (RAP) was utilized as part of our sustainability efforts, allowing us to reuse existing materials and reduce the demand for new raw materials. Zeolite was included for its ability to facilitate the production of Warm Mix Asphalt (WMA) by lowering the required production temperature, contributing to energy savings and reducing environmental impact. Finally, we selected bitumen with a penetration grade of 60/70 as the binding agent, known for its optimal balance of flexibility and durability, which is crucial for the performance of the asphalt pavement.

3.1.2 Properties

The materials used in our study were characterized by their specific gravity, with each component playing a vital role in the overall performance of the asphalt mixture. The coarse aggregates, sized at 20 mm and smaller, had a specific gravity of 2.79, while the fine aggregates, ranging from 0 to 5 mm, exhibited a specific gravity of 2.64. The filler material used in the mix had a specific gravity of 2.71, and the Reclaimed Asphalt Pavement (RAP) had a specific gravity of 2.19.

In terms of mechanical properties, the Aggregate Impact Value (AIV) was measured at 14.75%, indicating the resistance of the aggregates to sudden impact or shock. The Flakiness Index, which measures the proportion of flaky particles in the aggregate, was found to be 18.5%, while the Elongation Index, representing the percentage of elongated particles, was 16.8%. Additionally, the Angularity Number, which reflects the degree of sharpness or angularity of the aggregates, was determined to be 7.

3.1.3 Bitumen Properties:

The bitumen used in our study was Bashundhara 60/70 grade, selected for its suitable performance characteristics in asphalt mixtures. This bitumen had a flash point of 316°C, indicating the temperature at which it could vaporize to form an ignitable mixture in the air. The fire point, the temperature at which it could sustain combustion, was slightly higher at 320°C.

The loss on heating was measured at 0.54%, demonstrating the minimal weight loss when the bitumen is exposed to high temperatures. The specific gravity of the bitumen was found to be 1.0258, reflecting its density relative to water. The ductility, a measure of the bitumen's ability to deform under tensile stress without breaking, was 100 cm, indicating good flexibility. Lastly, the softening point of the bitumen was recorded at 48.6°C, which is the temperature at which it begins to soften and flow, critical for understanding its performance under heat.

3.2 Method:

The mix design composition used for Trial 1 is stated below:

Table 1

Trial 1: (Hot Mix Asphalt)

Particle Size	Percentage	Proportioned Weight
0 -5 mm	25%	300 gm
5 – 20 mm	40%	480 gm
RAP	30%	360 gm
Filler	5%	60 gm
Total	100%	1200 gm

Bitumen Amount is 5% of the total weight.
Bitumen heated at 150° Celsius temperature.

Produced Specimen:

	Specimen 1	Specimen 2	Specimen 3
Diameter	**101.43 mm**	**101.01 mm**	**101.52 mm**
Height	64.42 gm	1197.1 gm	1227.5 gm
Wt in Air	1257.2 gm	1197.1 gm	1227.5 gm
Wt in Water	746.1 gm	711.5 gm	729.05 gm

Table 2

Trial 2:

Particle Size	Percentage	Proportioned Weight
0 -5 mm	30%	360 gm
5 – 20 mm	35%	420 gm
RAP	30%	360 gm
Filler	5%	60 gm
	100%	1200 gm

Bitumen Amount deducted to 3.5% (As the RAP contains portion of old bitumen so we have deducted the Bitumen amount to reduce the flow value) and Bitumen heated at 150° Celsius temperature.

	Specimen 1	Specimen 2
Diameter	**100.567 mm**	**100.68 mm**
Height	63.9 mm	62.88 mm
Wt in Air	1235.2 gm	1193 gm
Wt in Water	711.6 gm	704.77 gm

Table 3

Trial 3: (WMA incorporating Zeolite and RAP)

Particle Size	Percentage	Proportioned Weight
0 -5 mm	30%	360 gm
5 – 20 mm	35%	420 gm
RAP	30%	360 gm
Filler	5%	60 gm
	100%	1200 gm

Bitumen Amount deducted to 3.5%. (As the RAP contains portion of old bitumen so we have deducted the Bitumen amount to reduce the flow value)
Zeolite Amount considered to be 4% by the mass of Bitumen.
Bitumen heating temperature reduced to 130° Celsius.

Diameter	101.25 mm	101.26 mm
Height	61 mm	68 mm
Wt in Air	1120.2 gm	1187 gm
Wt in Water	643.6 gm	682.2 gm

3.3 Marshall Stability and Flow Test Procedure:

3.3.1 Sample Preparation For Mix Design:

1200 gram of the dry mixed aggregates were measured for each specimen. To get rid of the extra moisture on the aggregates' surface, they were heated to 180 °C for an hour. This aids in a thorough coating, which further guarantees a uniform composition. Simultaneously, bitumen was cooked in the oven for at least an hour at a particular temperature. At room temperature, bitumen behaves like a solid because it is a semifluid. The bitumen must be heated in order for it to apply as a binder.

For trial 1 and 2 the temperature was set to 150° C and for trial 3 it was reduced to 130° C. The marshall mixing machine was also pre heated at a temperature of 160° C. The heated aggregate and the heated bitumen were then added into the marshall mixing machine.

3.3.2 Adding Bitumen Additive (Zeolite):

Trial 3 involved lowering the bitumen's heating temperature to 130°C. The zeolite was heated and then added to the bitumen, gently mixing it in with a steel spoon. The binder was supplemented with 5% of the bitumen's weight in zeolite. Trial 3 follows exactly the same procedures as trials 1 and 2, with the exception of adding zeolite to the binder.

3.3.3 Mixing:

Mixing was done using machine BM-10 a marhsall mixing machine for 2.5 minutes maintain a mixing temperature of 148° to 160° Celsius. This machine has a handle that rotates and ensures a homogenous mixture of the specimens.

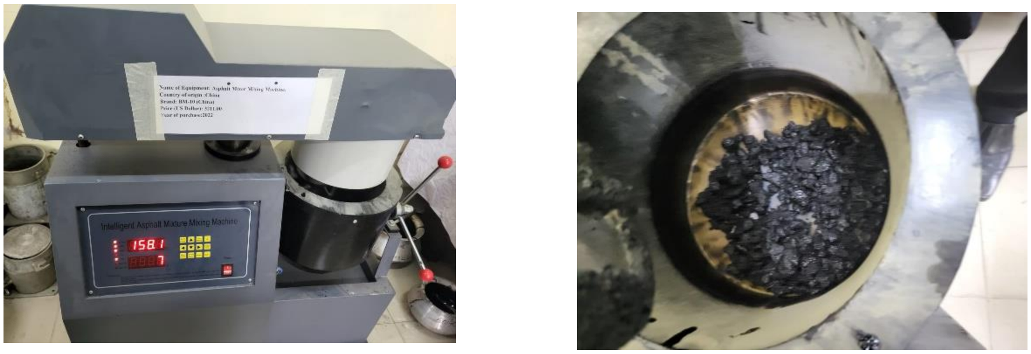

Figure 2: BM 10 Marshall Mixing Machine

3.3.4 Compaction

An automatic compactor ensures that asphalt samples are compacted equally and consistently throughout the production of warm mix asphalt (WMA). Through time and labor savings, testing procedures become more productive. Precise control and application of compaction force yields dependable test results and is essential for evaluating WMA's attributes. It aids in quality control by ensuring the mix meets the standards for stability and durability by producing consistent specimens for assessing various performance parameters.

The compaction was done using Automatic Compactor machine. Mold and collar were properly placed on the machine and the heated mixed aggregate were safely placed on the machine. 2 filter papers were placed properly on both side of the sample. Considering high traffic condition 75 blows were given to each side of the sample. The hammer is dropped from a height of 1 m. Here we get a cylindrical shaped specimen with a diameter of 6” and height of 4”.

Figure 3: Automatic Compactor and Mold- Collar Adjustment

3.3.5 Resting Period

Following sample preparation, the samples are let to rest at room temperature for one day. To guarantee precise and trustworthy results, asphalt specimens are given a day's rest prior to stability tests. During this rest period, the specimens can come to room temperature, the asphalt binder can solidify and harden, and internal stresses can be released. It also guarantees uniform diffusion of moisture throughout the mixture. The aforementioned variables serve to enhance the precision of the asphalt's long-term performance and preserve uniformity and comparability among various specimens and tests.

3.3.6 Asphalt Mold Extraction

After the resting period the asphalt samples are then extracted using a asphalt mold extractor.

Figure 4: Mold Extractor

3.3.7 Measurement of Sample Property

Diameter and height of samples are measured. The measurement is made for the weight under water and under air. It will help to calculate the void ratio of sample. The specific gravity of each sample is determined afterwards.

3.3.8 Water Bath

The samples were then put in water for 30 minutes with the temperature being kept at 60°C from the water bath machine. In WMA design, water bath machine is used to cure asphalt specimens at a desired temperature, usually about 60°C or 140°F, by submerged specimens in water. It is in such a controlled environment that the samples attain thermal equilibrium to ensure a uniform temperature within the asphalt mix. Such heating will homogenize the temperature of the specimens and remove temperature variations that could affect the test results, as would be obtained in testing Marshall stability and flow. The water bath machine provides very accurate information on the behaviour of asphalt material under real temperature settings by replicating the conditions asphalt will face in the field. This helps in choosing mix designs for durable and high-performance road surfaces.

Figure 5: Water Bath Machine

3.3.9 Marshall Stability and FlowTest:

Inserted the specimen into the Marshall stability testing apparatus correctly. applied a weight at a certain pace till it breaks. recorded the specimen's maximum load in kilonewtons (kN), or the Marshall stability value. The flowmeter was positioned above the guiding rods and the sleeve was firmly pressed up against the upper part of the breaking head as the force was applied. To determine the precise breaking point, a camera filmed the entire process. The flow value was then computed in millimeters (mm) units.

Figure 6: Marshall Machine and Prepared Specimen

Chapter 4 Result and Discussion:

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Specimen	Stability	Flow
1	9.882 kn	4.55 mm
2	10.212 kn	5.00 mm
3	8.325 kn	6.77 mm

Table 4: Trial 1 Results (HMA)

Specimen	Stability	Flow
1	13.15 kn	5.15 mm
2	12.93 kn	5.07 mm

Table 5 : Trial 2 Results (HMA + RAP)

Specimen	Stability	Flow
1	15.03 kn	3.17 mm
2	15.95 kn	2.98 mm

Table 6: Trial 3 Results (WMA+ RAP)

The results were obtained from the marshall machine. The specimens undergoes an increasing load under the machine and it also measures the load and stability of the specimens until the specimen fails. After the failure point the load decreases.

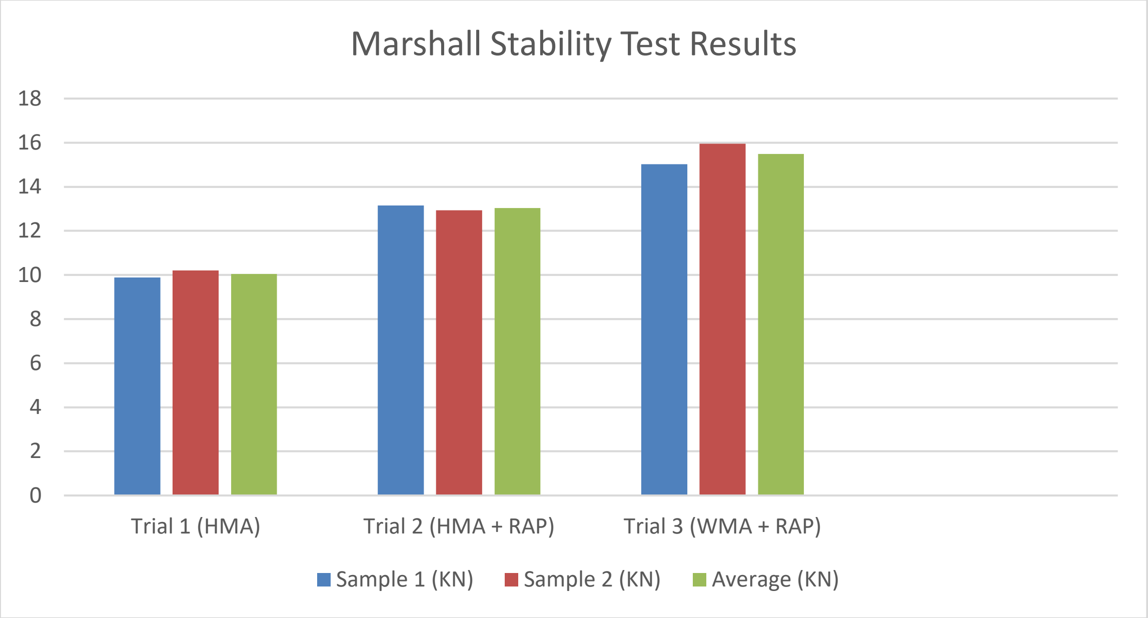

Figure 7 : Stability Result Comparison Chart

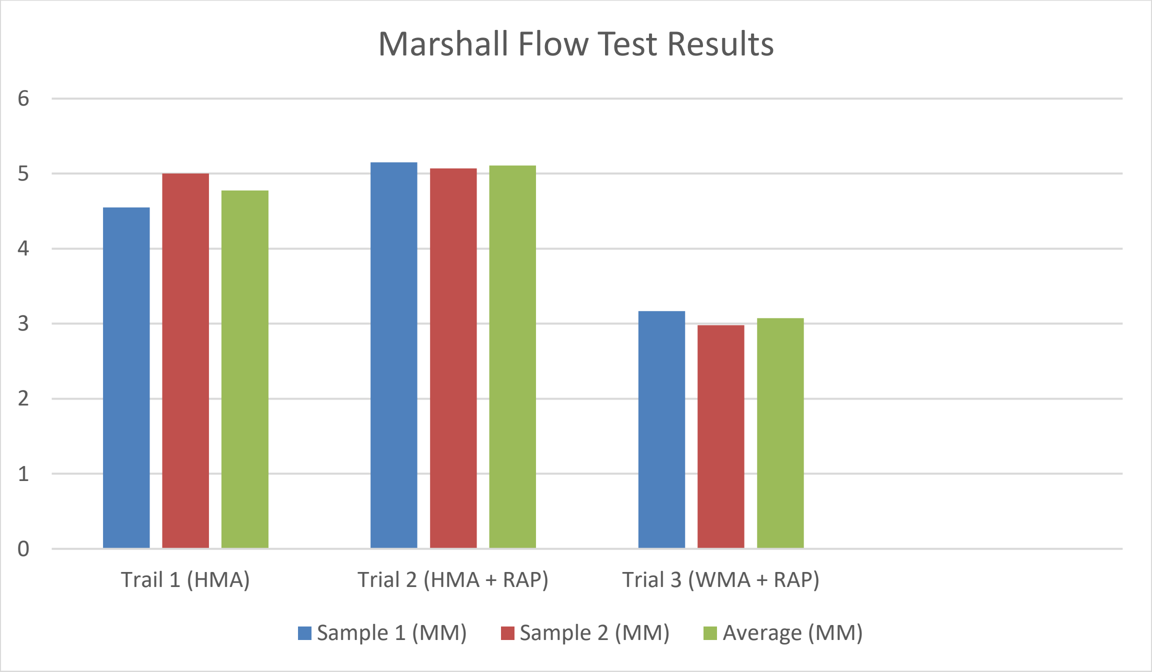

Figure 8 : Flow Result Comparison Chart

Discussion:

Trail 1 showed an average flow value of 5.44 mm and an average stability of 9.43 KN. Higher strength can be seen by this stability number, whereas excessive flexibility is indicated by the flow value, the sample is too soft. AASHTO T 245 states that the ideal flow value is between

2 and 4.5 mm. We had to adjust the mix design in order to minimize the flow value and boost stability. In this trial the specimen is not up to the standard, this is due to the higher void ratio caused by using larger aggregates.

In trial 2 we included more smaller aggregates (0–5 mm) in our subsequent mix design Since there appears to be more void. The average flow value in trial 2 is 5.11 mm, indicating that the sample is still overly flexible and soft, while the average stability was 13.04 KN, indicating a steady situation in terms of stability The addition of small particles and the decrease in voids have improved the stability. RAP is what we used for trial 2. The older bitumen present in RAP particles was the cause of the increased flow value. The bitumen content used here can be controlled, but the bitumen content present in RAP can not be controlled or measured with accuracy. So the selection of RAP needs to be as accurate as possible to control the flow value

In trial 3, to get a lower flow value and a lower bitumen amount, we had to select particles with less bitumen surrounding them. In order to attain greater stability, we also had to include larger RAP particles. Here, adding zeolite and reducing the bitumen amount worked as an optimizer. After adding the zeolite (WMA Additive), the bitumen's heating temperature was decreased to 130° Celsius. The deduction of temperature didn’t make the sample results unfavorable. As the temperature was decreased, we can call it WMA. Because of reducing the bitumen amount the flow value had dropped to 3.075 mm which indicates sample is properly flexible and has adequate flow. Regarding the higher percentage of larger particles chosen from RAP, it resulted in higher stability 15.049 KN which indicates the sample has high stability.

Chapter 5 Conclusion

Building and maintaining road infrastructure has always been a costly endeavour, requiring large quantities of natural aggregates and bitumen, which are non-renewable resources. The traditional process of manufacturing hot mix asphalt (HMA) requires a lot of energy which results in high levels of carbon emission because it entails heating and combining materials at elevated temperatures. Consequently, the industry is looking for other means of production that have less environmental impact due to several reasons including rising costs of raw materials as well as depleting quality aggregates supplies found in many areas. Warm Mix Asphalt (WMA) technology is one such innovation that has been developed away from the conventional hot mix technology. Through flexible production and application temperatures, WMA saves energy during the production process and also minimizes the emission of greenhouse gases. In addition, it helps in the reduction of greenhouse gases emissions and provided better condition for labor through avoiding exposure to high heat and toxic fumes during absorbing the solar energy. Also, the addition of Reclaimed Asphalt Pavement (RAP) into the mix also builds the sustainability of the process. RAP comprises unhardened bitumen and aggregates from previous layings of asphalt, thereby reducing call for virgin materials. Thus, through the application of RAP, the industry can limit the usage of natural resources, save energy and minimize the quantity of garbage disposed of. In our research we tried to create WMA using zeolite and RAP and the result was satisfactory. So in conclusion for this research we can say

- Bitumen heating temperature dropped by 20°C when zeolite was added.
- Required Bitumen amount becomes less while using RAP because it contains a portion of previously used bitumen.
- Using RAP particles reduces dependency on natural aggregate and resources.
- The advantages of warm mix asphalt (WMA) technology, which include lower energy use, lower emissions of carbon dioxide, better working conditions, and favorable environmental effects.
- Reclaimed asphalt pavement can reduce the quantity of material that should be disposed of in landfills by using RAP.
- WMA incorporating RAP reduces the production temperature without compromising on the properties of the bituminous mix.

To sum up, the combination of Reclaimed Asphalt Pavement (RAP) and Warm Mix Asphalt (WMA) is a promising development in environmentally friendly road building. The performance and longevity of asphalt pavements can be improved while simultaneously lowering energy consumption and greenhouse gas emissions during production, as this research has highlighted. Stakeholders of the transportation industry can enjoy huge savings and contribute to environmental efficacy with uncompromised pavement quality when they can harness the interactions of WMA and RAP. Future further research and field testing will be required to refine such technologies to their best performances under many situations, before the industry in general can boast of the wide adoption of such technologies. The future of asphalt technology seems to be in a good position to resolve economic and environmental issues through relentless innovation and collaboration to ensure the longevity of infrastructure.

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