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Performance Evaluation of Bituminous Emulsion Cold Mix

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Abstract

HMA for road construction is energy-intensive.Energy consumed during production and compaction of mix resulting emission of carbon and other harmful fumes and gases.The construction using traditional paving methods becomes challenging in rainy, snowy, hilly, and rural areas.Rainy seasons and hilly rural areas pose challenges for HMA pavement construction due to plant shutdowns and long transportation distances.The production temperature of Cold Mix Asphalt(CMA) is 0 – 40℃ which is very low comparing with Hot Mix Asphalt. We can generate cold mix on-site, utilizing either a basic concrete mixture, motor pavers, or specialized mixing plants for its production. In order to eliminate the emissions by hot mix plant while preparing hot mix, the temperature can be lowered by applying cold mix technology, an alternative to hot mix design. Also, cold mix technique can be beneficial where heating of aggregate might be a problem and the distance between the asphalt production plant and particular site is far. This research discusses the formulation of cold mixtures designed for various layers of pavements. The document offers insights into use of additive as cement (1-2)% commonly employed to enhance the performance of cold mixtures.The study aimed to determine the Marshall property of the cold mix using Emulsion as a binder. The stability and flow value were found to be 6.6 KN and 7.2 mm for mix with conventional filler respectively. The air void was found to be 3.5%. The Optimum Emulsion Content was found to be 7.73 for conventional filler and then gradually decreased in addition with cement.As the conventional filler was added by cement, the Marshall stability value increased by 5.17% and flow value decreased by 4.16%.

Keywords

Cold Mix, Emulsion, Cold Mix Bituminous Emulsion, Marshall Stability, Flow Value

1. Introduction

1.1 Background

The Paris Agreement (PA) is the locally binding international treaty on climate change signatories on 2015 [1] and its ultimate objective is to limit the global temperature increase to well below 2°C. Hot Mix Asphalt (HMA) pavements make up a significant portion of the country's paved roads, comprising a substantial part of the economy and typically manufactured within the temperature range of 150°C to 180°C [2]. This heating range is to attain proper coating of aggregates and improve workability of mix, however, resulting to energy consumption, release of CO2, and utilization of other environmentally harmful materials. As the trend of emitting carbon and harmful gases is more noticeable in the transport sectors during the production of Asphalt Concrete (AC) [3], Warm Mix Asphalt and Cold Mix Asphalt are some represent established alternatives that lowers the production temperature range in comparison with Hot Mix [4].

CMA is typically manufactured by blending emulsified bitumen, cutback bitumen, or foamed bitumen with aggregates, all without the need for heating. Unheated aggregates which are used in CMA makes it economical and relatively pollution free. The production temperature for CMA falls within 0-40°C range [5]. Due to the low production temperature, significant amount of energy can be saved [6]. Cold mix paving simplifies rural road construction in cold, remote areas, eliminating the need for heating and allowing on-site production even in adverse weather [7]. The Marshall method for designing asphalt aggregates with emulsified asphalt is founded on research conducted at the University of Illinois. It can be employed for creating base course mixtures suitable for areas with low traffic loads, as well as surface courses suitable for roads with moderate traffic volumes [7]. The test specimen's bulk specific gravity, Marshall stability, and the flow of the dry specimen are assessed using the Marshall test apparatus. However, there are some drawbacks associated with Cold Bituminous Emulsion Mix (CBEM) such as lower initial strength and lower moisture susceptibility [8]. Therefore, researchers have incorporated 1-2 % of Ordinary Portland Cement (OPC) by the aggregate's mass, resulting in a notable enhancement in the mechanical strength of Cold Mix Asphalt (CMA) [6]. Portland cement and lime are commonly added in emulsion mixes at 1-3% of the dry aggregate weight that enhance emulsion breaking for better binding of bitumen to aggregate, as extensively researched by various scholars [7]. Cement and lime have been generally added to CEAM in order to improve the engineering characteristics based on the fast bitumen emulsion coalescence that followed by compaction, development of bitumen viscosity and cement hydration[9]. Incorporating 1-2% of ordinary Portland cement (OPC) significantly enhances the initial mechanical characteristics of the mixture [10]. Marshall stability value is the maximum force that is recorded during the compression load and the test of stability for CBEMs was conducted on the sample which had been modified, compacted by using the apparatus of Marshall Stability [10]. In this study, regular stone dust is added with cement and Marshall test is performed. Again, Marshall stability, flow value and percent air voids are determined once the cold mix samples are prepared. The result thus obtained are compared based upon the conclusion and recommendations have been given.

1.2 Objectives of Study

The main objective of the research is to evaluate the performance of mix while preparing CMBM. The specific objectives are enlisted below:

- To analyze the various mechanical and physical properties of materials used in Cold Mix Bituminous Macadam.
- To compare the Marshall properties like Marshall stability and flow value adding Ordinary Portland Cement to stone dust.

2. Literature Review

Hot Mix Asphalt is the conventional method employed in the road construction sector and is typically manufactured at a temperature of 160°C [11]. The primary issue linked to HMA, stemming from its elevated production temperature, is the generation of greenhouse gases, which has a detrimental effect on the environment [12].

According to the Asphalt Institute, Warm Mix Asphalt is a modified form of HMA that is created, applied, and compacted at a temperature range that is 10 – 40°C lower than the traditional HMA mixture. This temperature range typically falls between 140°C to 180°C. WMA permits the mixing at asphalt plants to occur at reduced temperatures[13]. In regions with heavy rainfall and snow, traditional rural road construction is complicated due to the challenges of working with Hot Mix Asphalt. On-site cold mix production offers a practical solution for these challenging rural areas, tackling issues like rainy seasons, hilly terrain, and budget limitations. Basic equipment like concrete mixers, motor pavers, or dedicated mixing plants can be used. Unlike plant-produced hot mix, which can solidify before reaching the site, cold mix can be applied even in wet or humid conditions[7]. Cold mix pavement offers the potential for more than a 50% reduction in energy consumption compared to hot mix, making it a sustainable option for constructing rural roads [14]. In emulsion mixes, common additives such as Portland cement and lime are typically incorporated at a rate of 1 to 3 percent of the total weight of dry aggregate. An additive introduces certain charges to the emulsion, facilitating a faster breaking process where bitumen droplets are released from the emulsion [15].The inclusion of 1% Portland cement in CMA can lead to a significant increase in Marshall stability, ranging from 250% to 300% when compared to the untreated mixture [16].Additionally, the introduction of cement in cold mix asphalt accelerates emulsion breaking because cement hydration consumes water in the emulsion and meanwhile it increases its alkalinity[17]

3. Methodology

3.1 Materials

3.1.1 Aggregates

Crushed stone aggregates including both coarse and fine aggregates was obtained from Tikabhairav, which is major source around Kathmandu valley confirming aggregate gradation provided by Standard Specification for Road and Bridge, 2073, Section 1300, Clause 1313 Table 13.39. The adopted aggregate gradation table is as shown in Table 1.

Table 1: The adopted aggregate gradation

Sieve Size	Weight Retained	Cumulative Weight Retained	Cumulative Percent Retained	Percent Passing (%)	Required Gradation
26.5	0	0	0	100	100
19	435	435	2.82	97.18	90-100
13.2	2765	3200	20.78	79.22	56-88
9.5	4790	7990	51.88	48.12	20-55
4.75	3680	11670	75.78	24.22	16-36
2.36	1410	13080	84.94	15.06	4 to 19
0.3	1610	14690	95.39	4.61	2 to 10
0.075	375	15065	97.82	2.18	1 to 4
Pan	335				

The aggregate gradation curve followed for the study is as shown in Figure 1.

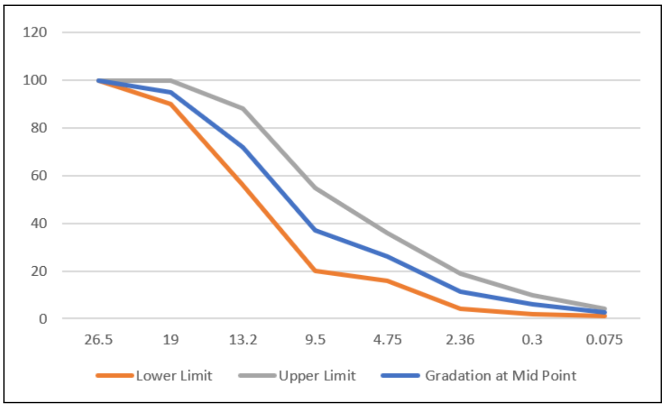

Figure 1: Adopted Aggregate Gradation

The physical properties of aggregates were tested and verified according to Standard Specification for Road and Bridge Works (SSRBS, 2073, Section 1300, Clause 1308, Table 13.26).

Table 2: Test on Aggregate

Property	Test Method	Limiting Value	Result
Los Angeles Abrasion Value	IS: 2386 Part 4	Max 30%	22.69%
Aggregate Crushing Value	IS: 2386 Part 4	Max 35% for Wearing Course	22.44%
Impact Value	IS: 2386 Part 4	Max 27%	13.23%
Specific Gravity of Coarse Aggregate	IS: 2386 Part 3	2.5 to 3.0	2.58
Specific Gravity of Fine Aggregate	IS: 2386 Part 3	2.5 to 3.0	2.67
Flakiness Index	IS:2386 Part 1	Max 35%	21.66%

3.1.2 Emulsion

The aggregates used were crusher run aggregate and free from clayey particle. So, bitumen binder with a 65% residual bitumen content, specifically a Cationic Medium setting (MS-2) emulsion, was utilized in the mix preparation. The sample was collected from Nepal Bitumen Barrel. The coating test of aggregates shall be carried out as per ASTM D 2397. The various properties of emulsion are used for the test and verified as per Standard Specification for Road and Bridge Works (Section 1300, Clause 613, Table 6.15), are enlisted as below in Table 2:

Table 3: Test on Emulsion

Property	Test Method	Limiting Value	Result
Residue on 600-microne Sieve %	IS: 1887	0.05	0.02%
Viscosity at 50 C, Saybolt Furol Viscometer (Seconds)	IS: 3117	30 - 300	72 seconds
Particle Charge	IS: 8887	Positive	Positive
Test on Residue			
a) Penetration at 25°C, Min	IS: 1203	60-150	74 mm
b) Ductility 27°C, Min	IS: 1208	50	81.75 mm
c) Specific Gravity	IS: 1202		1.019

3.1.3 Filler

The filler component must comprise finely pulverized mineral substances like rock dust, fly ash, hydrated lime, or cement. Cement having specific gravity 3.04 is used as filler materials. Cement used for the study is collected from local cement supplier. The basic properties of filler materials were tested and are listed in Table 3:

Table 4: Test on Filler

Property	Test Method	Limiting Value	Result
Specific Gravity of Cement	ASTM - 4318	3.1 to 3.16	3.04
Fineness Percent	ASTM C150	Minimum 90%	99.04%

3.2 Water Content Determination

When emulsion is used to prepare emulsion aggregate mix, Water is incorporated into the mixture [6]. The objective of adding additional water is to improve the evenness of the aggregates, resulting in enhanced workability and better coverage of the aggregates. As per Standard Specification for Road and Bridge (2073), the water used in CMBM should be potable. The ideal water content for pre-mixing was established by conducting tests involving both aggregate coating and the dry density method. The Optimum Water Content (OWC) obtained by dry density method was 6.5% and OWC proceeded with the coating test was 3%. Further, 3% water content was finalized by visual observation.

3.3 Marshall Specimen Preparation

The process outlined by the Asphalt Institute was adhered to when creating the cold mix samples. Various size of aggregates was blended together to achieve specified aggregate gradation. These aggregates were made wet by adding optimum water content i.e.3%. The proposed aggregate gradation with conventional filler was mixed with five different binder content 5.0%, 6.0%, 7.0%, 8.0% and 9.0% (DOR, 2017, Section 1300, Clause 1313) to determine the Optimum Emulsion Content. In cold mix design, design temperature generally ranges from 0 to 40°C [6]. The mixture was left to dry for 1 to 2 hours. Thus, prepared mixture was then transferred into the Marshall mold compacted with 50 blows of Marshall hammer on both faces. The samples were extracted from mold by the help of extrusion jack. Thus, obtained samples were left to dry at room temperature for one day. Additionally, the specimens were placed in an oven at a temperature of 40°C for a duration of 72 hours.After 72 hours, the test specimen was subjected to water only for 1 to 2 minutes for Saturated Surface Dry (SSD) and after taking necessary weights of the sample, they are subjected to dry Marshall test (DOR, 2073). The flow value, bulk density, void content, void filled with binder, etc. were further calculated. Later on, similar procedure was followed but this time 1-2% cement was added on the conventional aggregate gradation and their Marshall properties were evaluated.

3.4 Marshall Test

The Marshall experiments were conducted at the civil engineering laboratory located at Viswa Consult in Dillbazar. Following the preparation of the Cold Mix Bituminous Macadam, the Marshall test was conducted using the standard procedure for assessing the Marshall stability and flow properties of bituminous mixtures.The connection between bitumen content and various mixture characteristics, such as air voids and bulk specific gravity, was examined to ascertain the Optimum Emulsion Content (OEC).

4. Result, Analysis and Discussion

Marshall test was conducted for the adopted aggregate gradation as shown in Figure 1. The stability value in cold mix design increases and then decreases with the increasing emulsion content. As the emulsion content rises, there is an observable increase in the flow value of the test specimen. Similarly, unit weight was calculated and found to be increasing with increasing amount of emulsion. The variation of stability value, flow value and unit weight with increasing emulsion content is as shown in Figure 2.

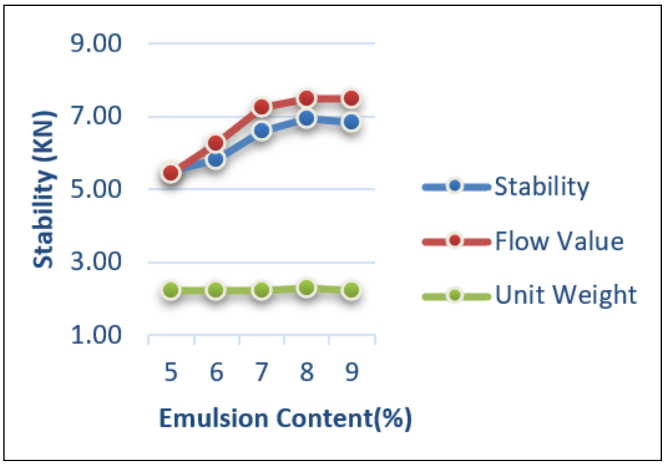

Figure 2: Emulsion Content Vs Marshall Stability, Unit Weight and Flow Value

Likewise, Figure 3 illustrates how the air voids, VMA (Voids in Mineral Aggregate), and VFB (Voids Filled with Bitumen) change as the emulsion content varies. It was found that air voids remained in the range of 3-5%, VMA got decreased whereas VFB got increased with the increase in bitumen emulsion. The VMA and VFB variation was analysed from graph in figure 4.

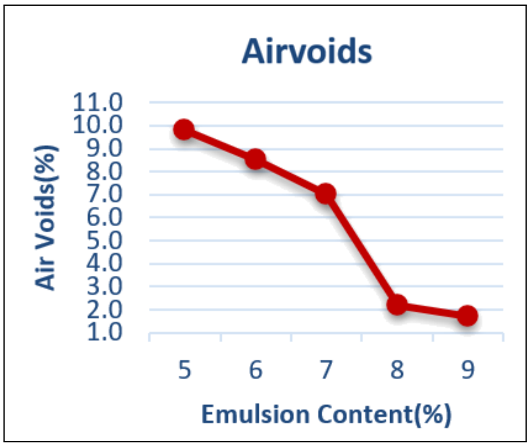

Figure 3: Emulsion Content Vs Air Voids

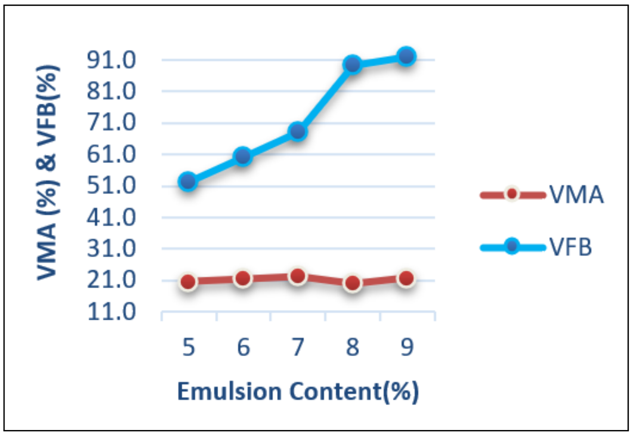

Figure 4: Emulsion Content Vs VMA and VFB

Again, the test was performed by adding 1-2% cement content the result was analyzed from the graph shown in Figure 5, Figure 6, Figure 7 and Figure 8. The stability value consistently continues to rise and falls within the range of 6 to 8 kilo-newtons (KN). Similarly, the flow value falls within the range of 6 to 8 mm. Further, air voids were calculated and was observed to be 4% and 4.2% for 1% and 2% cement respectively and is shown in figure 8.

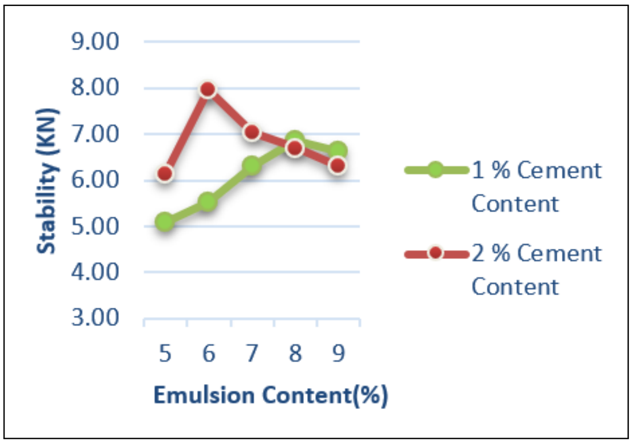

Figure 5: Emulsion Content Vs Stability Value

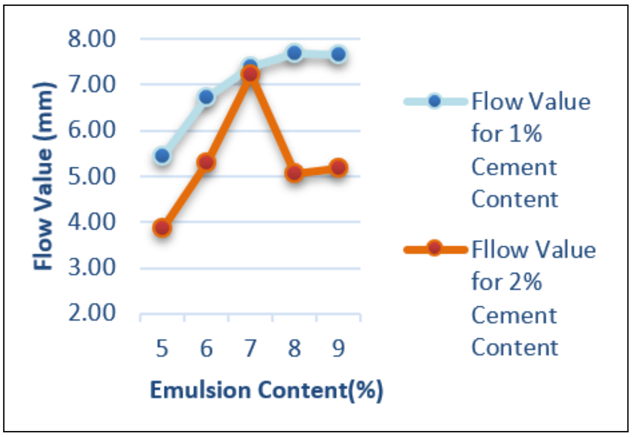

Figure 6: Emulsion Content Vs Flow Value

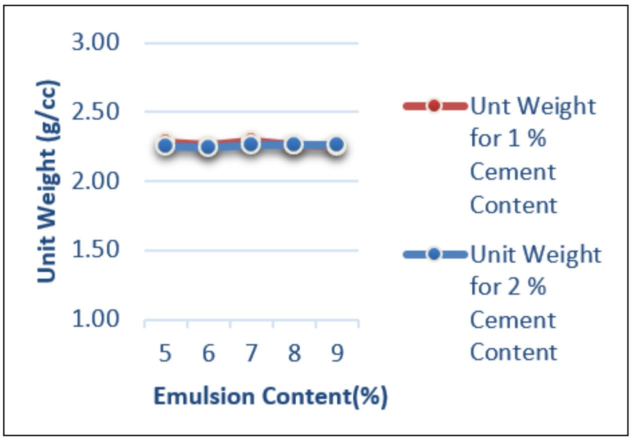

Figure 7: Emulsion Content Vs Unit Weight

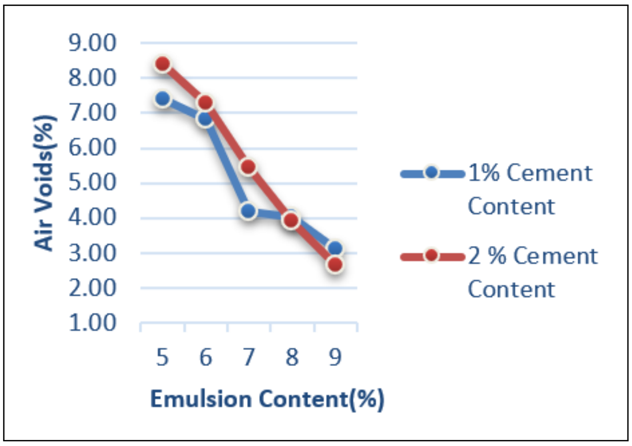

Figure 8: Emulsion Content Vs Air Voids

From Figure 9 and Figure 10, the VMA and VFB value was analyzed and found that the value increases with the increasing cement content as well as emulsion content.

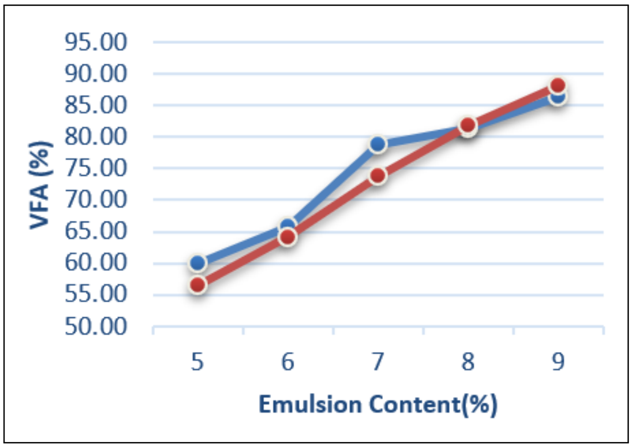

Figure 9: Emulsion Content Vs VMA

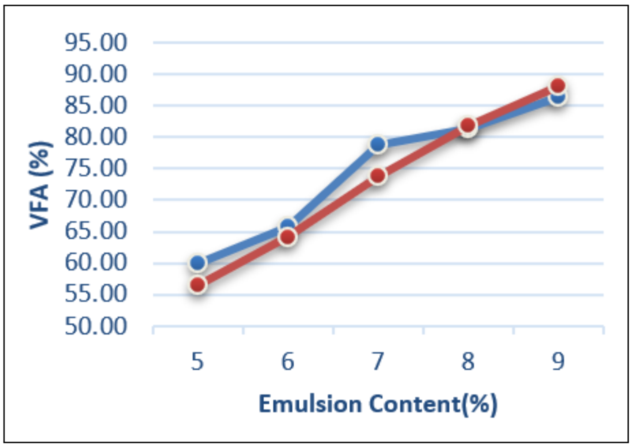

Figure 10: Emulsion Content Vs VFB

5. Conclusion

Consequently, based on the aforementioned outcomes and analysis, we can conclude that bituminous emulsion cold mix can be used as a structural layer. Further additional tests were conducted adding cement as filler materials which gives satisfactory value for Marshall stability and Marshall flow. Further findings drawn from the experiment can be concisely summarized as follows:

- Optimum Emulsion Content (OEC) for the mix with conventional was found to be 7.73%. The OEC gradually decreases as the conventional filler is added by cement.
- At Optimum Emulsion Content, properties of all the mixes were determined, analyzed and compared. Marshall stability and flow value were found to satisfy the standard specification (SSRB, 2073).
- Marshall stability value was found to be 6.6 KN for mix with conventional filler. The stability value gradually increased to 7 in addition with cement and was found to be higher than minimum limit recommended by SSRB(2073).
- Marshall flow Value was found to be in range of 7mm to 8 mm which is below the maximum limit recommended by SSRB(2073).

6. Recommendation

From the research, it is recommended that cold mix also can be used in structural layer i.e., base layer without being limited to patching and maintenance work as it satisfies the Marshall stability and flow value recommended by SSRB, 2073. The air void percentage for the convention filler was found to be lower than that of recommendation provided by SSRB, 2073. Thus, the limiting range should be rectified to the range of 3 to 5% for the given aggregation for CMBM by SSRB, 2073. (Section 1300, Clause 1313, Table 13.39). Further study can be conductted by adding fillers with varying cement percentage or other filler materials like lime, fly ash, etc. It is advisable to conduct additional research involving different variations in aggregate gradation. It is also recommended to adopt cold mix technology for low volume road.

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