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# Experimental Study on Bituminous Emulsion Mix

**by**

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# APPROVAL PAGE

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The undersigned certify that they have read and recommended to Institute of Engineering for acceptance, a thesis entitled **"Experimental Study on Bituminous Emulsion Mix"** in partial fulfillment of the requirement for degree of Master of Science in Transportation Engineering.

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# ABSTRACT


Paris Agreement (PA) is a treaty made between different countries worldwide and aims to hold the increase in average temperature below 2 ˚C. PA mainly focuses on climate related capacity building as it is realized that transport sector is majorly contributing in carbon emission. Hot Mix asphalt covers large part of nation's surface road which needs a lot of energy consumption during production and compaction of mix resulting emission of carbon and other harmful fumes and gases. With an aim of lowering the production temperature and emission rate, cold mix technology was developed. The production temperature of cold mix is 0 – 40 ˚C which is very low comparing with hot mix. In areas prone to heavy rainfall and snow accumulation, the colder environmental temperatures create challenges in heating both aggregate and binder to the necessary high temperatures. The construction of rural roads using conventional paving techniques becomes problematic due to the intricate processes required for producing and applying Hot Mix Asphalt. In such situations, an alternative solution is to use cold mix, which can be produced directly at the construction site. Simple concrete mixers, motor pavers, or specialized mixing plants can be employed to generate cold mix on-site. In order to eliminate these emissions, 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%.

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| | |
|---|---|
| AASHTO | American Association of State Highway and Transportation Officials |
| AC | Asphalt Concrete |
| ACV | Aggregate Crushing Value |
| AIV | Aggregate Impact Value |
| ASTM | American Society for Testing of Materials |
| BM | Bituminous Macadam |
| CMBM | Cold Mix Bituminous Macadam |
| CBEM | Cold Bituminous Emulsion Mix |
| CEAM | Cold Emulsion Asphalt Mix |
| CFA | Coal Fly Ash |
| CMP | Cold Mix Plant |
| CMA | Cold Mix Asphalt |
| DOR | Department of Road |
| GHG | Greenhouse Gas |
| HMA | Hot Mix Asphalt |
| HMP | Hot Mix Plant |
| IEC | Initial Emulsion Content |
| KN | Kilonewton |
| MORTH | Ministry of Road Transport and Highway |
| MQ | Marshall Quotient |
| MS | Marshall Stability |
| MS | Medium Setting |
| SS | Slow Setting |

| | |
|---|---|
| OBC | Optimum Bitumen Content |
| OEC | Optimum Emulsion Content |
| OLTC | Optimum Total Liquid Content |
| OPC | Ordinary Portland Cement |
| OPWC | Optimum Premix Water Content |
| ORBC | Optimum Residual Bitumen Content |
| PA | Paris Agreement |
| SDBC | Semi Dense Bituminous Concrete |
| SDBM | Semi Dense Bituminous Macadam |
| SSRB | Standard Specification for Road and Bridge Works |
| SSD | Saturated Surface Dry |
| USACE | US Army Corps of Engineers |
| VFB | Voids Filled with Bitumen |
| VMA | Voids in Mineral Aggregates |
| WMA | Warm Mix Asphalt |

# CHAPTER 1: INTRODUCTION

## 1.1 Background

The Paris Agreement (PA) is the locally binding international treaty on climate change signatories on 2015 (Cochran, 2019) to limit the global average temperature, to increase the ability to adapt the adverse impacts of climate change and to regulate the finance flows that increases with the impact of climate change. The trend of emitting carbon and harmful gases is more noticeable in the transport sectors during the production of Asphalt Concrete (AC) (Costaa and Benta, 2016).

Based on the production temperature, asphalt mix is generally categorized into three groups: Hot Mix Asphalt (HMA), Warm Mix Asphalt (WMA), and Cold Mix Asphalt (CMA) (Al-Busaltan et al. 2012). HMA pavements constitute a large part of Nepal's paved surfaced roads and covers larger economy of the nation. In order to attain proper coating of aggregates and improve workability of mix, the hot mix is heated at 150 ˚C to 180 ˚ C (Milad, et. al., 2022). The production of Hot Mix Asphalt involves a substantial amount of energy consumption, leading to the emission of CO2 and other environmentally harmful materials. The emissions resulting from traditional hot mix asphalt production consist of an intricate combination of fumes, vapors, and solid particulate matter (Florkova, et.al., 2021). The fumes produced by HMA can also pose health risks for road workers and employees at asphalt plants. Research indicates that the production temperature of HMA significantly influences the levels of polycyclic aromatic hydrocarbons and other pollutants associated with HMA. Therefore, the production technology of Hot Mix Asphalt (HMA) is widely employed, with its primary drawbacks being the requirement for elevated mixing temperatures and the generation of greenhouse gas emissions.

On the other hand, Warm Mix Asphalt is manufactured by reducing the temperature, typically by approximately 20–40 °C, in comparison to the conventional Hot Mix Asphalt temperature range of 140–190 °C (Rathore, et. al. 2021). Warm Mix Asphalt (WMA) technologies are categorized into three main groups, which encompass foaming processes, organic additives, and chemical additives (Kamaruddin and Zamhari, 2012).

To control carbon footprint, another new technology naming Cold Mix Asphalt (CMA) has been adopted. CMA is typically created by combining emulsified bitumen, cutback, or foamed bitumen with aggregates without the need for heating. CMA is generally produced by mixing emulsified bitumen, cutback or foamed bitumen without heating aggregates. Unheated aggregates which are used in CMA makes it economical and relatively pollution free. The production temperature of Cold Mix Asphalt (CMA) falls within the range of 0-40 °C (Frank, et. al. 2012). Due to the low production temperature, significant amount of energy can be saved (Jain and Singh, 2021). In areas characterized by substantial rainfall and snow accumulation, the lower environmental temperatures pose challenges in heating both aggregate and binder to high temperatures. Consequently, the construction of rural roads using traditional paving methods becomes difficult due to the intricacies associated with producing and applying Hot Mix Asphalt (Choudhary, et. al. 2012). CMA is largely used for minor construction, repair works rural road construction and roads having low traffic density (Jain and Singh, 2021). Cold Bituminous Emulsion Mix (CBEM) has certain disadvantages despite these significant benefits, including lower initial strength, greater voids, lesser moisture susceptibility, etc. (Prasad, et. al 2022). In order to solve these issues, scientists added Ordinary Portland Cement (OPC) to aggregate at a mass percentage of 1 to 2. This greatly increased CMA's mechanical strength, and after CMA had fully cured, its mechanical characteristics were discovered to be superior to those of HMA (Jain and Singh, 2021). Curing time is one of the key factors that determines the mixture parameter; Cold Emulsion Asphalt Mix (CEAM) has a number of downsides and needs two months to two years to reach its maximum strength (Shanbara, et. al., 2017). In order to enhance the bitumen emulsion's engineering properties, cement is added to CEAM. This is followed by compaction and the growth of bitumen viscosity (Shanbara, et. al., 2020). In this study, conventional filler was added with by OPC and Marshall test was performed. Marshall stability, flow value and percent air voids were determined once the cold mix samples were prepared. The result thus obtained were compared based upon the conclusion and recommendations have been given.

## 1.2 Problem Statement

The process of constructing asphalt pavement has a notable effect on the environment, as it results in the release of greenhouse gases and increased energy consumption (Feng Ma, et. al., 2016). Hot Mix design is generally adopted in asphalt pavement and is produced at relatively high temperature ranging 138ºC–160 ºC (Sargand, 2009). The high temperature is used to dry the aggregate, increase workability and decrease the viscosity of the asphalt binder, allowing it to fully coat the aggregate. The study finds that the mixing and drying of aggregate for the pavement (48%) uses the most energy from extraction to asphalt placement. Furthermore, around 40% of all energy is used in the production of bitumen (Feng Ma et. al. 2016). The heating temperature required for the production of HMA is mainly responsible for the emission of various gases like Carbon monoxide, Sulphur dioxide, Nitrogen oxide, Carbon dioxide and so on. Cold Bituminous Emulsion Mix (CBEM) is commonly used for minor construction, repairs, and rural roads with low traffic density due to its advantages. However, CBEM has drawbacks like low initial strength, higher voids, and susceptibility to moisture. Researchers have addressed these issues by adding 1-2% Ordinary Portland Cement (OPC) by mass of aggregate, significantly enhancing CMA's mechanical strength. After full curing, CMA's mechanical properties surpass those of Hot Mix Asphalt (HMA). In case of Kathmandu and peripheral area, the asphalt production plant is limited in number and the cost of fuel required to prepare the mix is quite high. When HMA is supplied from a remote HMA plant on hilly rural roads, it can be challenging to maintain mix temperature over long hauling distances. It is more difficult to heat aggregate and binder at high temperatures in high altitude, snow-bound, and high rainfall regions due to the lower ambient temperature. Hence, cold mix can be an alternative since it can be created on location using a specialized mixing plant, motor pavers, or a basic concrete mixture (Choudhary, et. al. 2012). In order to eliminate these emissions, 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.

## 1.3 Research objectives

The main objective of the research is to evaluate the performance of mix while preparing Cold Mix Bituminous Macadam (CMBM).

The specific objectives of the research are:

a) To determine and analyze the various mechanical and physical properties of materials used in CMBM.
b) To determine the Optimum Emulsion Content (OEC).
c) To compare the Marshall properties like Marshall stability and flow value adding OPC to conventional filler.
d) To calculate the approximate emission of carbon while producing cold and hot mix.

## 1.4 Scope of study

The study was initiated conducting a literature review to identify the methods that involves in finding the Marshall properties of mix as well as mechanical properties of materials. The Marshall properties of CMBM are determined to calculate the Optimum Emulsion Content (OEC). The mechanical and physical properties of Cold Mix Bituminous Macadam (CMBM) are evaluated as well as performance of CMBM is tested by adding OPC on it. The procedure of preparation of mix and the test performed are described in the methodology. The study offers a thorough and comparative analysis of cold mix design as a greener substitute for traditional hot mix technology.

## 1.5 Assumption and Limitations

The assumptions and limitations of the research works are as follows:

a) The aggregate obtained from the same source was supposed to have uniform properties.
b) Single gradation of aggregate was used.
c) Only single type of emulsion was used throughout the study.

d) The long-term performance of CMBM in terms of its resistance to rutting and moisture damage was not mentioned in the research.

## 1.6 Organization of report

The project report consists of 5 chapters as follows:

Chapter 1: Introduction describes about the subject matter, outlining the background, the problem statement, the study's objective, and its limitations.

Chapter 2: Literature Review provides idea of different literatures in the related area.

Chapter 3: It makes clear about the adopted methodology to meet the required objectives of work.

Chapter 4: Results and Discussions are presented in this chapter.

Chapter 5: Conclusions and Recommendations are explained up in this chapter.

All the experimental records and calculations are provided in Appendix 1 to Appendix 5.

# CHAPTER 2: LITERATURE REVIEW

## 2.1 Asphalt Pavement as a Greenhouse Gas Emitter

Base course paving began using asphalt emulsion more frequently in the 1970s as a result of growing traffic volumes, the oil crisis, and environmental preservation (Terrel and Wang, 1971). Feng Ma et. al. (2016) studied about the asphalt pavement construction and its environmental impact. He mentioned, though there are no any proper criteria to evaluate the Greenhouse Gas (GHG) emission, a method of evaluation from asphalt pavement construction could be the one. He further studied for the evaluation of GHG emissions for construction process of Asphalt Mixture Course. The production of raw materials, mixing, transportation of the mixture, paving, and rolling of the asphalt mixture account for the total greenhouse gas emissions in CO2 equivalent. During this process, the energy consumption of manufacturing plants and machinery was used to calculate the greenhouse gas emissions (Feng Ma et. al. 2016). He mentioned, during the mixing phase, the hot asphalt mixture's gas emissions, the energy used by the mixing equipment to heat the aggregate and asphalt binder, and the equipment itself all contribute to greenhouse gas emissions. This leads to the consumption of fossil fuel in the aggregate and asphalt heating system resulting generation of gases like CO2, CH4 and N2O. These emissions are primarily accountable for contributing to global warming (Gandhi, 2008).

## 2.2 An Alternative to Conventional Hot Mix Asphalt

The method most frequently employed in the road construction sector is called hot mix asphalt (HMA), which is created at 160ºC (Jorda et. al., 2008). The primary issue with HMA stemming from its elevated manufacturing temperature is the generation of greenhouse gases that have a detrimental effect on the environment (Ghale and Pataskar, 2017).

The Asphalt Institute states that WMA is a modified HMA mixture that is created, applied, and compacted between 10 – 40º C colder than the typical HMA mixture, which is between 140º C to 180º C.

By lowering the temperature during production and construction, WMA technology could reduce carbon footprint and emissions while improving performance and creating a healthier environment (Frank et. al. 2012). There are three primary WMA technology types that are commonly utilized globally: chemical, organic, and foam bitumen additives (Vaitkus et. al. 2009). WMA has been shown to perform better in terms of reducing oxidative hardening, block cracks, and thermal cracks (Hurley and Prowell, 2005). Research was done at the Highway and Transportation Laboratory, University Tun Hussein Onn Malaysia, on the potential of warm mix asphalt technology with liquid surfactant. Warm mix asphalt was created using liquid surfactant as an additive, with a recommended dosage of up to 0.4% of the binder weight (Kamaruddin and Zamhari, 2012). WMA enables the production of asphalt plant mixing at a lower temperature (Timothy et. al.). It will use less energy than HMA and result in a 30% reduction in carbon dioxide emissions, a 50%–60% reduction in dust emissions, and a reduction in greenhouse gas emissions (Frank B et. al. 2012).

In regions with heavy rainfall and snow bound area, the construction of rural roads using traditional paving methods becomes challenging due to the complexities involved in producing and applying HMA (Choudhary, et. al. 2012). In India, a significant portion of the road infrastructure is covered by bituminous pavement, with HMA being the primary choice for road surfacing for many years (Choudhary, et. al. 2012). This bituminous mixture does have certain restrictions, though. Some of these include the HMA plant's excessive emissions of greenhouse gases (such as sulfur dioxide, nitrogen oxides, carbon monoxides, and volatile organic compounds), the hot mix plant's closure during the rainy season, the difficulty of laying HMA in hilly and rural areas with long hauling distances, the high cost of installing HMA plants compared to the relatively low budgets of small rural road sections, etc. On-site production of cold mix is achievable. Basic concrete mixing equipment, motor pavers, or dedicated mixing plants can all be utilized to create cold mix directly at the construction site. (Choudhary, et. al. 2012). Cold mix when used as paving mix can eliminates heating of aggregate and binder. (Choudhary, et. al. 2012). When compared to hot mix, cold mix pavement can save more than 50% on energy consumption; for this reason, it can be regarded as a green bituminous mix for building rural roads (Doyle, T). The paving mix is especially well-suited for building roads in isolated and distant parts of the country, where hot mix produced by the plant may have set before arriving at the site and cold mix can be laid in humid or wet conditions (Choudhary, et. al. 2012). The Marshall Method for emulsified asphalt aggregate design is based on University of Illinois research and can be used in surface course for roads with low to medium traffic volumes and base course mixture for roads with low traffic loads (Choudhary, et. al. 2012). The MORTH specification's emulsion content guidelines can be used to prepare the specimen (2001). Specimens are cured for one day at room temperature in the mold and for one day at 38°C in the oven after removal from the mold. Using a vacuum apparatus, specimens are soaked in water before being tested for soaked stability. Using the Marshall Test apparatus, the test specimen's bulk specific gravity, Marshall Stability, and flow of the dry specimen, as well as its soaked stability and flow of the wet specimen, are determined (Choudhary, et. al. 2012).

Chelelgo, et. all in 2018, suggested a new technology named as Cold Mix Asphalt (CMA). Since there is no need for aggregate heating during this process, CMA is affordable and comparatively pollution-free (Al-Busaltan et al. 2012). CMA, also known as bitumen emulsion asphalt, is a sustainable, eco-friendly, and energy-efficient replacement for hot-mix asphalts. Bitumen is emulsified by mechanically dispersing small globules of hot penetration-grade bitumen in water with the help of emulsifiers that are negatively or positively charged. Bitumen globules are positively charged (cationic), negatively charged (anionic), or neutrally charged (nonionic) by the emulsifiers, which helps to maintain their continuous suspension in water (Salomon, 2006). Hot-mix asphalts are produced by blending aggregates elevated temperatures, while cold-mix asphalts are produced emulsified or foamed bitumen at ambient temperatures (Chelelgo, et. al., 2018). He used virgin aggregates with bitumen emulsion composed of 65% bitumen and 35% water and he further carried Marshall test preparing Marshall specimen at varying premix water and emulsion. To evaluate its performance in comparison to a structural wearing course layer, the Marshall test is employed (Usman K. R. et.al., 2020). The specimen was cured for one day and cured in oven at 40˚C for 72 hours before being de-molded. Cold asphalts have several advantages over hot-mix asphalts, including lower costs, greater energy efficiency, and environmental friendliness. However, they also have drawbacks, such as longer curing times, higher air-void contents, and lower early-life strengths (Thanaya et. al., 2009). In a separate study, Thanaya reported that bitumen emulsions, as opposed to penetration grade bitumen, could save up to 40% on energy costs during the production of asphalt. According to a study by Oke et al. (2014), using cold reclaimed asphalt pavement mixtures instead of hot-mix asphalt could result in savings of 40% to 60%. Despite all these positive environmental and economic effects, CMA has not been used much up to this point, mostly for rural road construction and low-traffic roads due to stability and durability issues (Jain and Singh 2021). Using cold mix has certain drawbacks, such as increased moisture susceptibility, higher voids, and lower early life strength (Thanaya, 2007). Cement increased the resistance to permanent deformation in CMA, according to Al-Busaltan et al. (2012). The Marshall stability of CMA can be increased by 250–300% with the addition of 1% Portland cement when compared to an untreated mix, as demonstrated by a study by Dulaimi et al. (2017), who also suggested that the cement-modified mix could be used for important pavement layers.

The amount of residual bitumen needed for initial strength is known as the initial residual bitumen content (IRBC), and it can be calculated using the provided equation (MS-14, 1997).

$$IRBC = (0.05A + 0.1B + 0.5C) \times 0.7 \tag{2.1}$$

Where, the variable X represents the bitumen content of the emulsion. The variables A, B, and C represent the percentage of coarse, fine, and filler material, respectively, that is retained on a 2.36 mm sieve, a 0.075 mm sieve, and a 2.36 mm sieve, respectively.. According to (Jain and Singh, 2021), there are two ways to find the optimal premix water content. The initial test is the coating test, where samples are made by adding 0.5% more water to each sample. The water content that yields the maximum aggregate coating while maintaining a mix that isn't overly thick or runny is referred to as OPWC. Usually through visual observation. The second technique, known as the maximum dry density method, prepares samples by adding more water to them. Every sample's dry density is calculated, and the water content at which the maximum density is reached is referred to as OPWC.

Samples are prepared and then allowed to sit in molds for a full day before being extruded. After that, the samples are kept in an oven for 24 hours at 40 °C. After being divided, the molds are kept at room temperature for a day (Dash and Panda, 2018). Samples for HMA must be soaked in a water bath at 60℃ for 30 to 40 minutes. However, samples for CMA cannot withstand the curing temperature of 60℃ due to their low initial strength (Jain and Singh, 2021). The mix's optimal residual bitumen content is the amount at which Marshall stability is at its highest (MORTH, 2013). The MORTH air void range of 3–5% is not realistically achievable. Additionally, Chelelgo et al. (2018) ascertained moisture susceptibility, bitumen emulsion content, ideal total fluid content, aggregate gradation, Initial Emulsion Content (IEC), and moisture-density relationships. A cylindrical specimen is subjected to an indirect tensile strength test to determine its splitting strength. This test is conducted by applying a compression load diametrically on the specimen at a constant rate of 50.8 mm/min. Steel strips are used on the top and bottom of the specimen to create a tension zone that passes through the center of the load (Zainab and Al-Hdabi, 2021). The value of the maximum tensile strength calculated as below:

$$\sigma\, t = \frac{2Pmax}{\pi HD} \quad \text{…………...Equation 2}$$

Where:

σ t = indirect tensile strength, KPa;

P max = ultimate applied load, KN;

H = specimen height, m;

D = specimen diameter, m.

The test of stability for CBEMs was performed on the sample that had been modified and compacted using the Marshall Stability apparatus. The Marshall stability value is the maximum force that is recorded during the compression load (Zainab and Al-Hdabi, 2021). The samples were extracted from the mold and then treated for 24 hours at 40 ° C in the oven. The samples were then left for five days. Before the test is conducted on the sixth day, the object is placed in the oven for at least two hours at 40°C (Zainab and Al-Hdabi, 2021). According to what he said, the Marshall flow value is the deformation recorded at maximum load at constant rate of 50.8mm (2 in) per min that applies synchronization with the Marshall Stability test. This occurs when holding the sleeve firmly against the upper segment of the breaking head, at which point the flow meter was zeroed and the test started. The Marshall flow is the depth of the plastic flow resistance to bituminous mixture specimens that are loaded on the lateral surface using the Marshall apparatus.

## 2.3 Cold Mix Asphalt and its Performance with other Filler Materials

In a study by Thanaya (2009), cement was added at a rate of 2% to the aggregate's total weight to increase strength and meet stiffness. The study's findings suggested applying cold mixes in the summer or during the dry season. The two most common additives found in emulsion mixes are lime and Portland cement. Usually, one to three percent of the dry aggregate's total weight is made up of these additives. An additive introduces certain charges to the emulsion, facilitating a faster breaking process where bitumen droplets are released from the emulsion. These bitumen droplets then adhere to the aggregate, enhancing binding characteristics. In 2000, Brown and Needham conducted research on emulsion mixtures that were modified with cement. Their primary aim in conducting the research was to assess the advantageous impact of incorporating Ordinary Portland Cement (OPC) into emulsified mixtures. The study's conclusions showed that adding OPC improved the mechanical properties of emulsified mixtures, taking them to new heights in terms of stiffness modulus, resistance to permanent deformation, and fatigue strength (Choudhary, et. al. 2012).

Due to the subpar quality of asphalt emulsion mixes in handling traffic loads, these pavements exhibited problems such as poor initial performance, reduced stiffness, and inadequate water stability. To address these issues, regular Portland cement (OPC) was incorporated into the asphalt emulsion mixture to enhance its initial engineering characteristics. The inclusion of cement enhances the connection between aggregates and emulsion, leading to better overall performance (Thanaya, et. al., 2009). In their 2010 study, Pundhir et al. employed a 2 percent OPC in cold mix design and compared Semi Dense Bituminous Concrete (SDBC) samples with 2 percent cement to neat samples that were drawn under various curing conditions. He discovered that the stability value of the cold mix containing 2 percent cement at 25°C was higher (966 Kgf) than the stability of the cold mix containing no cement at the same temperature (688 Kgf).

CEAM technology has been enhanced with a variety of additives to speed up the curing process and enhance mechanical properties (Shanbara et. al., 2021). Cement and lime have usually been added to CEAM in order to improve the engineering properties based on the fast bitumen emulsion coalescence that is followed by compaction, the development of bitumen viscosity, and cement hydration (Shanbara et. al. 2021). CEAM is used to shorten the curing period, improve the properties of the bituminous mixture, and then improve the performance of the mixture in terms of stiffness, workability, and flexibility (Shanbara et. al., 2017). Lime has been found to have significant ecological benefits when used as a filler in cold mix technology. When it comes to high plasticity, lime is thought to be the best modifier (Bocci et al., 2010). Because the asphalt emulsion mixes were of insufficient quality to support the loads from traffic. These pavements had problems with reduced water stability, reduced stiffness, and poorer early performance. In heavy-duty pavements, cold mix asphalt has rarely been utilized as the structural layer. To improve the early engineering properties of the asphalt emulsion mix, ordinary Portland cement (OPC) was added. Performance is enhanced when cement is added because it strengthens the bond between the aggregate and the emulsion (Thanaya et. al., 2009). The early mechanical strength of CMA was greatly increased by numerous researchers using Ordinary Portland Cement (OPC) 1-2% (by mass). After CMA had fully cured, its mechanical properties were discovered to be superior to those of HMA (Thanaya et. al., 2009). According to Al-Busaltan et. al. (2012), the addition of cement to CMA boosted its resistance to permanent deformation. Fly ash is one of the most widely used filler materials for enhancing the properties of concrete mixtures because of its cementitious property (Holland et. al., 2016). Additionally, fly ash is utilized in the construction of subgrades, road bases, and subbases. When fly ash is used in CBEMs (Cold Bitumen Emulsion Mixes), the volumetric properties and creep resistance are better and more appropriate than with a conventional mix (Jain and Singh.,2021). Fly ash was used to partially replace the stone dust in the CBEM by 1, 2, 3, 4, and 5% of the total aggregate weight (Prasad et. al. 2022). Further, he determined Initial Emulsion Content (IEC), Optimum Premixed water Content (OPWC), Optimum Total Liquid Content at compaction (OTLC), and optimum residual bitumen content (ORBC) and found that OTLC increased with increasing flyash content. Fly ash has a lower specific gravity than stone dust, which takes up more volume in the compacted mix and reduces the amount of space available for the bitumen (West and James, 2005). Water generally encapsulate in the compacted mix during early stage and tries to hinder the formation of bituminous bond with mineral aggregates (Jain and Singh 2021) which results in lower strength of the mix. The improvement in Marshsll Stability (MS) value may be due to the stiffening of mix occurred by the hydration of flyash in the presence of encapsulated water, which is considered as a secondary bond in the mix (Al-Busaltan et. al. 2012). The Marshal quotient (MQ), which mainly represents the stiffness of the mix, is calculated by dividing the MS value by the mix's flow value. A mix with a higher MQ value is more stiff, able to disperse applied load and resist creep deformation (Arabani and Azarhoosh, 2012). Additionally, it shows the mix's resistance to shear stress, ongoing deformation, and rutting behavior (Zoorob and Suparma, 2000). On the other hand, an extremely high MQ value indicates an extremely stiff mix, which can cause distresses such as fatigue cracking, bleeding, etc. Bringing up these concerns MORTH (2013) suggests that bituminous mixes have a MQ range of 2-4 kN/mm. Fly ash's free lime content may increase the bitumen aggregate's adherence and the bituminous mix's resistance to moisture (Choudhary et. al. 2020). The marshal stability, marshal quotient, and retained stability increased on increasing fly ash content (Prasad et. al. 2022). Because they are inexpensive and can enhance CBEM mechanical properties while also providing benefits to the economy and environment, waste and by-product materials have been used in place of cement in a number of experiments (Al-Hdabi et. al., 2013).

## 2.4 DOR Specification

Bituminous Macadam (BM), an open-graded bituminous mixture, is used to build bituminous base courses and is typically appropriate for roads with moderate traffic. Compacted mixture is used in one or more courses during the construction of Cold Mixed Bituminous Macadam (CMBM). Bitumen emulsion is used in its preparation. In order to prepare CEBM, bitumen emulsion must meet IS: 8887 requirements and be of Medium Setting (MS), Slow Setting (SS-2) grade, or specially made to be compatible with readily available mineral aggregates (ASTM or AASHTO). The characteristics of the aggregates. determines grade of the emulsion. The aggregates that are used for the be clean, strong, durable and disintegrated pieces, organic and other deleterious matter. Those crushed material which generally retains on 2.36 mm IS sieve are coarse aggregate. and those which retains on 75-micron sieve are fine aggregate. The combined aggregates used in CMBM must meet the specified gradation outlined in Table 2.1.

**Table 2.1 Grading Requirement of Combined Aggregate**

| Sieve Size (mm) | Percentage passing by weight |
|---|---|
| | for 50 mm thick |
| | CMBM |
| 26.5 | 100 |
| 19 | 90-100 |
| 13.2 | 56-88 |
| 9.5 | 20-55 |
| 4.75 | 16-36 |
| 2.36 | 4-19 |
| 1.18 | |
| 0.3 | 2-10 |
| 0.075 | 1-4 |

The design procedure of cold mix involves optimization of water and optimum bitumen emulsion content for the aggregates in the mix. The mixture must adhere to the specifications listed in Table 2.2.

**Table 2.2 Design Requirement for Cold Mix**

| Parameter | Cold Mix Bituminous Macadam (CMBM) |
|---|---|
| Number of compactions blows on each side of Marshall specimen | 50 |
| Marshall Stability at 25°C in kg (minimum), after curing the specimen at room temperature for 72 hours | 350 |
| Marshall flow (mm) | Max 8 |
| Per cent voids in mixture | 14-Oct |

The aggregates are first moistened by wetting their surface with water, and then cationic bitumen emulsion is applied. The best standard gradation of BM or SDBC is achieved by blending different sizes of aggregates in desired proportion. Physical tests are then carried out to ascertain the properties, such as specific gravity, aggregate impact value, and water absorption value, following the sieve analysis. Similarly, testing of bitumen emulsion is performed as per IS: 8887. The water content at which the aggregate coats the best is known as the optimum water content. The binder then observes the coated aggregates to determine the area of the aggregate that has been coated. Normally, 2 to 3 percent of the aggregate's weight should be the ideal water content for BM or SDBC. To perform Marshall test, varying sizes of aggregates are blended to achieve the desired aggregate gradation. Marshall samples are prepared varying bitumen emulsion contents of 5, 6, 7, 8 and 9 percent by weight of aggregates.at optimum water content. After preparing the Marshall mold, the mold is subjected to oven for 72 hours at 40℃ and then subjected to Marshall test for flow and stability value at dry state at 25° C.

## 2.5 Marshall Test

Bruce Marshall in 1940 introduced the Marshall mix design method for the creation of hot mix asphalt. Since then, it has gained popularity for mixing asphalt concrete. During World War II, the technique was initially implemented by the US Army Corps of Engineers (USACE). To evaluate its performance in comparison to a structural wearing course layer, the Marshall test is employed (Usman K. R. et.al., 2020). Cylindrical specimens are prepared in various ratios that meet the minimum stability and flow requirements as well as the air void content (% av), voids in mineral aggregate (VMA), and voids filled with bitumen (VFB) requirements. The stability and flow numbers are related to the asphalt concrete mix's strength and flexibility. Research conducted by Mulatu et. al., (2021) performed Marshall test to determine properties of asphalt mix and Optimum Bitumen Content.

# CHAPTER 3: METHODOLOGY

## 3.1 Research Design

The methodology followed throughout the research work is shown in Table 3.1. The details of complete methodology followed as per standard codes and research articles mentioned in chapter 2. Before commencing the work, the literature was reviewed. Based on reviewed literature and observing the present scenario of Nepal, problem was identified. The objectives were and testing mentioned in Figure 3.1 were performed. The obtained values from the experiment were analyzed and further conclusion were drawn.

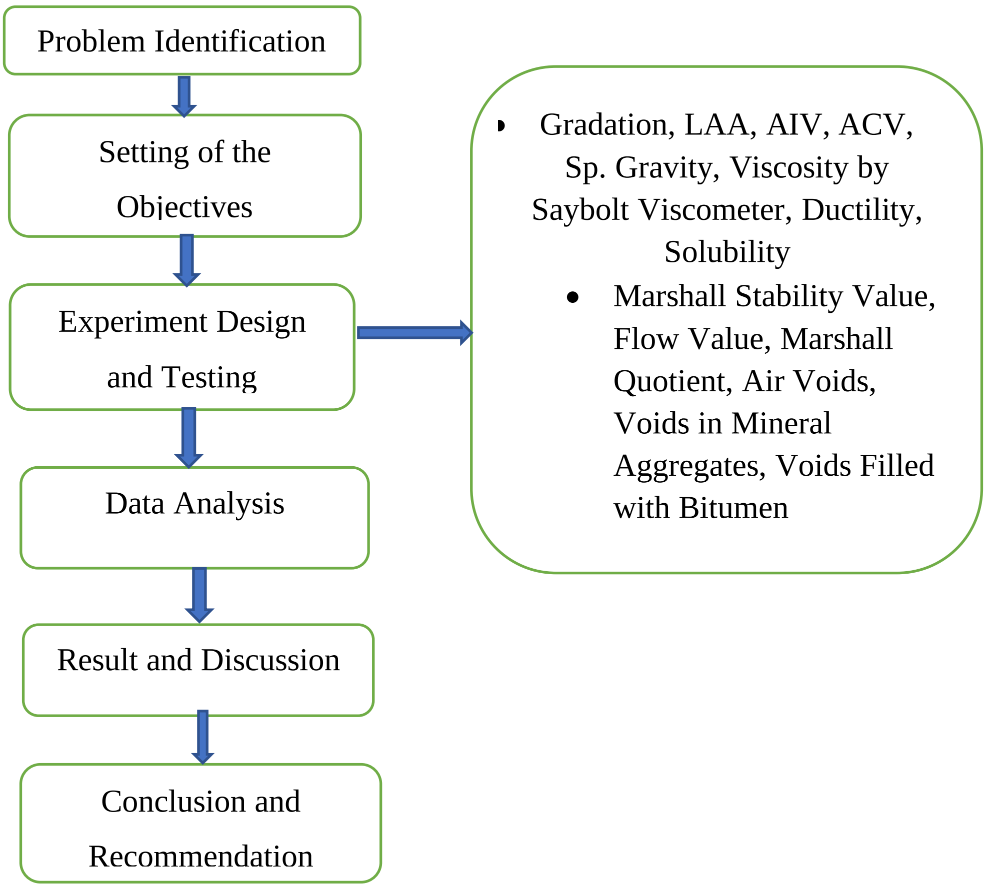


**Figure 3.1 Flow Chart of Research Design**

### 3.2 Sampling of Materials

Sample preparation followed a standard procedure and included steps are discussed below as:

The materials to be used in this study are enlisted as below:

i. Crushed stone aggregate (coarse, fine)
ii. Emulsion MS
iii. Cement
iv. Mineral filler (fly ash)
v. Water

### 3.3 Standards and Specifications for Study

The following paragraphs provide descriptions of all the materials used in this study:

#### 3.3.1 Aggregates

Crushed stone aggregates including both coarse and fine aggregates were obtained from Tikabhairav, which is the major source around Kathmandu valley confirming aggregate gradation provided by Standard Specification for Road and Bridge, Section 1300, Clause 1313, Table 13.39. Crushed material retained on a 2.36 mm IS sieve was used as coarse aggregate, and fraction passing through a 2.36 mm sieve and retained on a 75-micron sieve was used as fine aggregate (SSRB, 2073). The aggregates used for the test is shown in Figure 3.2.

**Figure 3.2 Aggregates Used for the Gradation Test**

At first, the physical properties of aggregates such as LAA, ACV, Impact test, etc. were tested and verified according to Standard Specification for Road and Bridge Works (SSRBS 2073, Section 600, Clause 613, Table 6.5).The results obtained from the lab test are listed in  Table 3.1

**Table 3.1 Test on Aggregates**

| 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 |
| Sodium Sulphate Soundness | IS: 2386 – part V | Min 12% | 7% |
| Flakiness Index | IS: 2386 – part 1 | Max 35% | 21.66 % |

Sieve analysis, gradation of aggregates, physical tests and specific gravity of aggregates are shown in Appendix 1, Appendix 2 and Appendix 3 respectively.

### 3.3.2 Aggregate Gradation for Study

When it comes to the particle size distribution specification guideline for CMBM production, the aggregate gradation should convince the control points. Initially, the aggregates were collected from nearby crusher and then the sieve analysis was performed. The total percent passing of aggregates was obtained after the calculation of total aggregates retained on the individual sieve. Based on the Standard Specification of Road and Bridge works 2073 (Section 1300, Clause 1313, Table 13.39), aggregate gradation curves were drawn so that the gradation convince the specification requirements. The aggregate gradation for the test was prepared with aggregate of nominal size 19mm. Gradation for 50mm layer thickness was fulfilled by suitable proportioning of aggregates. The adopted gradation is shown in Figure 3.3

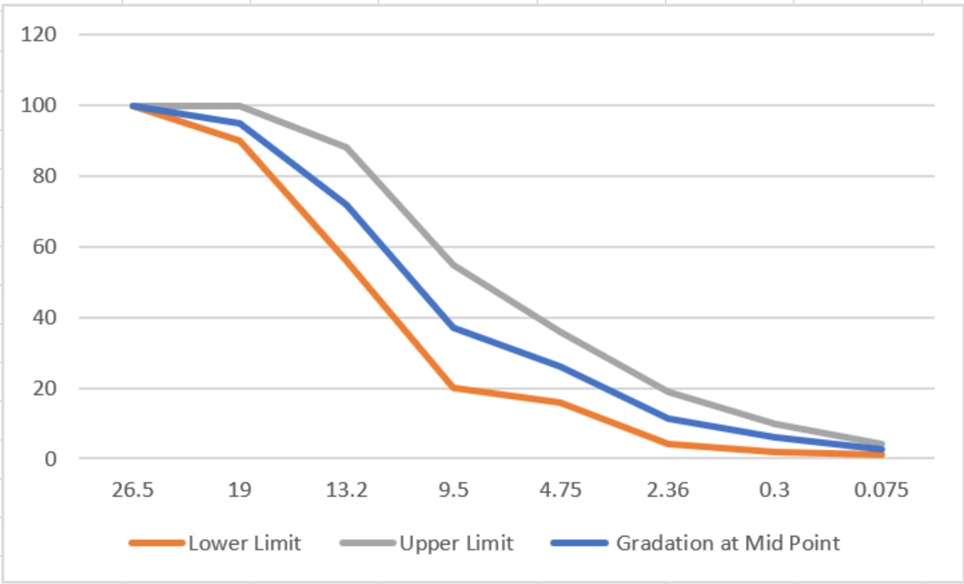


**Figure 3.3 Adopted Gradation Curve as per Specification**

Gradation limit required for the Cold Mix Bituminous Macadam (CMBM) following Standard Specification for Road and Bridge Works is tabulated in Table 3.2:

**Table 3.2 Gradation Limit as per Specification of Road and Bridge Works**

| Size (mm) | % Passing by Weight | |
|---|---|---|
| (mm) | Sieve Minimum | Maximum |
| 26.5 | 100 | 100 |
| 19 | 90 | 100 |
| 13.2 | 56 | 88 |
| 9.5 | 20 | 55 |
| 4.75 | 16 | 36 |
| 2.36 | 4 | 19 |
| 1.18 | | |
| 0.3 | 2 | 10 |
| 0.075 | 1 | 4 |

### 3.3.3 Binder

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 was carried out as per ASTM D 2397. The emulsion used for the test is as shown in Figure 3.4

**Figure 3.4 Emulsion for the Test**

The various properties of emulsion such as viscosity, penetration, ductility, specific gravity, etc. were tested and verified as per Standard Specification for Road and Bridge Works (Section 1300, Clause 613, Table 6.15), are enlisted as below in Table 3.3:

**Table 3.3 Properties of Emulsion:**

| Property | Test Method | Limiting Values | Result |
|---|---|---|---|
| Residue on 600-micron 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 | IS: 1203 | 60-150 | 74 mm |
| b) Ductility 27°C | IS: 1208 | 50 | 81.75 mm |
| c) Specific Gravity | IS: 1202 | | 1.019 |

### 3.3.4 Filler

Finely divided mineral materials, such as fly ash, hydrated lime, rock dust, or cement, were generally used as filler. In this study, cement was used as filler material. Cement used for the study was collected from local cement supplier. The cement used for the test is shown in Figure 3.5.


**Figure 3.5 Cement Used for the Test**

The basic properties of filler materials were tested and are listed in Table 3.4:

**Table 3.4 Tests on filler materials:**

| Property | Limiting value | Test Method | Result |
|---|---|---|---|
| Specific Gravity of Cement | 3.1 to 3.16 g/cc | ASTM-4318 | 3.04 |
| Fineness Percent | Minimum 90% | ASTM C150 | 99.04% |

### 3.3.5 Water

CMBM is manufactured at ambient temperature with the help of emulsion and water is generally mixed in case of emulsion. When emulsion is used, water is added in mix (Jain and Singh, 2021). According to the Standard Specification for Road and Bridge (2073), the water used in CMBM should be potable water. The purpose of the extra water is to lubricate the aggregates, which enhances their coating and workability. The application of water creates a wet aggregate surface, which improves the aggregate's ability to coat with binder (DOR, 2073) and improves the workability of the mix. The optimum water content for premixing was determined by performing both coating test and dry density method. The optimum water content obtained by dry density method was 6.5% which was not satisfactory. Further, we proceeded with the coating test and performed trial with 2%, 2.5% and 3% by weight of aggregate. And, 3% water content was finalized by visual observation.

### 3.4 Marshall Specimen Preparation

The sample specimens were prepared for cold mix as per Asphalt Institute Procedure (Chelelgo et. all, 2018). Various size of aggregates was blended together to achieve specified aggregate gradation which is shown in Figure 3.3. 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. Three specimens for each percentage of emulsion were prepared. In cold mix design, design temperature generally ranges from 0 to 40℃ (Jain and Singh, 2021). The mixture was left to dry for 1 to 2 hours (Figure 3.7). Thus, prepared mixture was then transferred into the Marshall mold (Figure 3.8) 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 (Figure 3.9). Further, the samples were kept in oven at 40̊ C for 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.

The test was repeated with the same procedure. But this time the conventional filler was supplemented with 1-2 % of Ordinary Portland Cement (OPC). The specimens were subjected to different Marshall stability test. Other than stability test, flow values and bulk density were also determined. Other parameter like void content, void filled with binder etc. were further calculated.

**Figure 3.6 Aggregates for Cold Mix**

**Figure 3.7 Sample after mixing with Emulsion**

**Figure 3.8 Marshall Mix**

**Figure 3.9 Marshall Sample**

**Figure 3.10 Sample Extracting from Mold by Extrusion Jack**

## 3.5 Marshall Test

The Marshall tests were carried out civil engineering laboratory of Viswa Consult, Dillbazar. After preparing the mix for Cold Mix Bituminous Macadam, the standard test procedure for bituminous mixture flow and Marshall stability was used to conduct the Marshall test. By using the Marshall Method, it was possible to determine the correlations between the bitumen content and the mixture's characteristics, including air voids, bulk specific gravity, VMA, VFA, stability, and flow.

**Figure 3.11 Marshall Mold**

The minimum requirement of Marshall properties for Cold Mix was taken as per references of the hot mix design that is provided in the Specification for Road and Bridge Works, 2073 under clause 1308. The following volumetric parameter were calculated after determining Marshall stability in KN and Flow value in mm.

i. Unit weight of specimen (G) – in gm/$cm^3$
ii. Percentage of air voids – in %
iii. Voids in Mineral Aggregate (VMA) – in %
iv. Voids Filled with Bitumen (VFB) – in %

### 3.6 Determination of Fuel Consumption and Carbon Emission

The amount of diesel oil required for the production of hot bituminous mix and cold mix by batching type asphalt plant was taken from technical specification provided by catalogue of ANP batch asphalt mixing plant. The total mix that a plant can produce plant was calculated as per Norms for Rate Analysis of Road and Bridge works, 2075 (section 1300, clause 1307). Similarly, Same norms (section 1300, clause 1313) was followed for the calculation cold mix produced by plant. The total diesel oil required by Hot Mix plant for full plant capacity was calculated. As per Norms for rate analysis of Road and Bridge Works, 2075 (Section 1300, Clause 1307), total bituminous mix produced in 6 hours was calculated. Further, amount of carbon emission was determined as per Federal Register (2010). Similarly, total diesel oil required by Cold Mix plant was and amount of carbon emission was calculated.

# CHAPTER 4: RESULT, ANALYSIS AND DISCUSSION

## 4.1 General

Initially, Marshall test was conducted for the adopted aggregate gradation as shown in Figure 3.2. The various graphs and tables were analyzed and results were drawn from the individual sets of Marshall test.

## 4.2 Marshall Stability Value Analysis

The stability value signifies the ability of an asphalt mixture to withstand deformation or rutting under traffic loads and high temperatures. The maximum stability that occurs with varying emulsion content is shown in Table 4.1. Marshall stability value was found to be 6.6 KN for mix with conventional filler. The stability value gradually increases with the increase in cement content was found to be higher than minimum limit recommended by SSRB (2073).

**Table 4.1 Variation of Stability Value with Different Emulsion Content**

| Emulsion Content (%) | Stability Value (KN) |
|---|---|
| 5 | 5.49 |
| 6 | 5.80 |
| 7 | 6.58 |
| 8 | 6.93 |
| 9 | 6.85 |

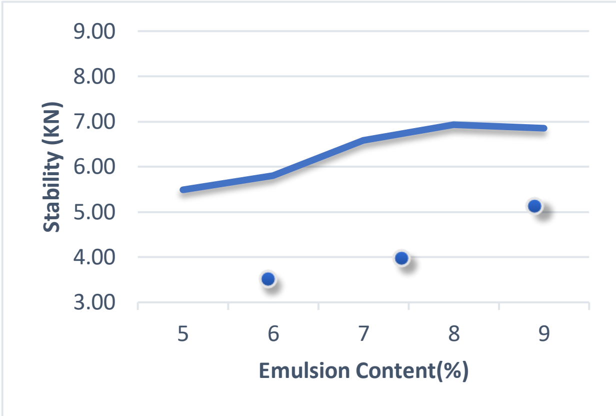


**Figure 4.1 Marshall Stability Versus Emulsion Content**

## 4.3 Flow Value Analysis

The test specimen's deformation during loading up to the maximum load is known as the flow value. The flow value of the test specimen increases as the emulsion content increases. The variation of flow value with the different emulsion content is as shown in the Figure 4.2. As per graph in Figure 4.2, the flow value obtained at OEC from the graph for the design mix was 7.2 mm which is below the maximum limit recommended by SSRB (2073).

**Table 4.2Variation of Flow Value with Different Emulsion Content**

| Emulsion Content (%) | Flow Value (mm) |
|---|---|
| 5 | 5.42 |
| 6 | 6.25 |
| 7 | 7.24 |
| 8 | 7.48 |
| 9 | 7.49 |

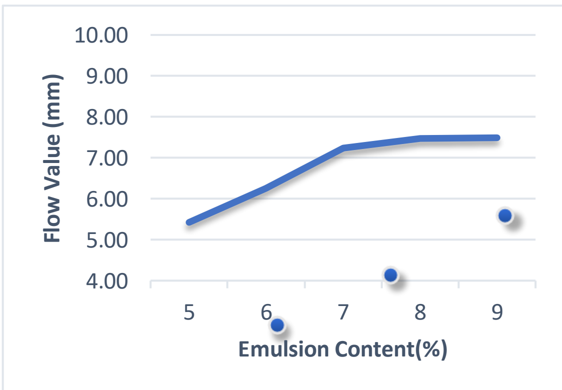


**Figure 4.2 Flow Value Versus Emulsion Content**

## 4.4 Unit Weight Analysis

Unit weight analysis in the Marshall Test is generally done to evaluate the density of asphalt concrete specimens. Unit weight analysis provides important information about the compactness and density of the asphalt concrete mix, which is crucial for assessing its durability and load-bearing capacity. Once the weight details of the specimen were obtained, the unit weight of the individual specimen was calculated. From Figure 4.3, the maximum unit weight was obtained at 8% emulsion content. The variation of unit weight with different emulsion content is as shown in Table 4.3 and Figure 4.4.

**Table 4.3Variation of Unit Content with Different Emulsion Content**

| Emulsion Content (%) | Unit Weight (gm/cm$^3$) |
|---|---|
| 5 | 2.22 |
| 6 | 2.22 |
| 7 | 2.22 |
| 8 | 2.30 |
| 9 | 2.24 |

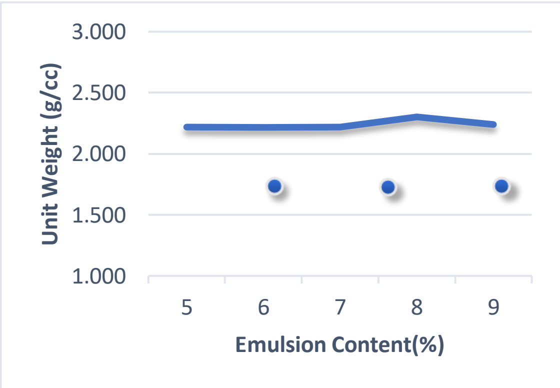


**Figure 4.3 Unit Weight Versus Emulsion Content**

## 4.5 Air Void Analysis

Air void analysis in the Marshall test is a fundamental aspect of asphalt mixture evaluation and design. Reducing the air voids in the mixture enhances its impermeability. Conversely, insufficient air voids can result in issues like rutting, shoving, flushing, or bleeding. The design air void level in a laboratory-compacted sample of HMA is 4 percent as per MS-2 Asphalt Mix Design Methods. But for Cold Mix, no such design air void is recommended in both MS-2 Asphalt Mix Design Methods and SSRB, 2073. So, air void analysis was done as per Hot Mix design. The variation of air void with different amount of emulsion content is as shown in the Table 4.4. The optimum emulsion content is determined at 4% air voids. As the emulsion content increases, the air void in the mix decreases and was found to be 3.5% which was below the limit recommended by SSRB (2073).

**Table 4.4 Variation of Air Void with Different Emulsion Content**

| Emulsion Content (%) | Air Voids |
|---|---|
| 5 | 9.8 |
| 6 | 8.5 |
| 7 | 7.0 |
| 8 | 2.2 |
| 9 | 1.7 |

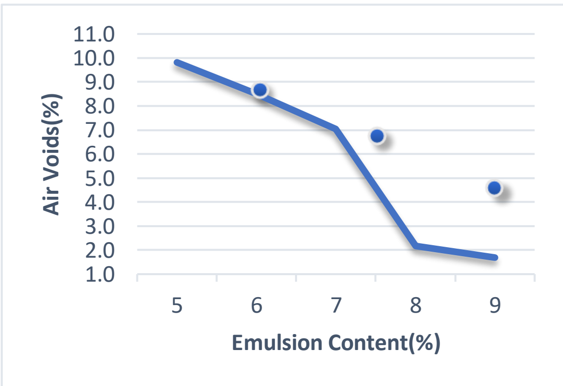


**Figure 4.4 Air Void Versus Emulsion Content**

## 4.6 Voids in Mineral Aggregate (VMA) Analysis

The empty space between the aggregate particles in a compacted mixture is represented by voids in the mineral aggregate. This measurement indicates how much room is accessible for the bitumen to effectively cover each aggregate particle. Initially, the Voids in Mineral Aggregate decrease as the emulsion content increases and then starts to increase. Asphalt mixtures with insufficient VMA will result in thin asphalt films and lead to less durable asphalt pavements. The variation of VMA with increase in emulsion content is sown in Table 4.5. The VMA obtained at OEC was 21% where the minimum limit is 13.0 percent recommended by MS-2 Asphalt Institute method.

**Table 4.5 Variation of VMA with Different Emulsion Content**

| Emulsion Content (%) | VMA (%) |
|---|---|
| 5 | 20.5 |
| 6 | 21.4 |
| 7 | 22.1 |
| 8 | 20.1 |
| 9 | 21.7 |

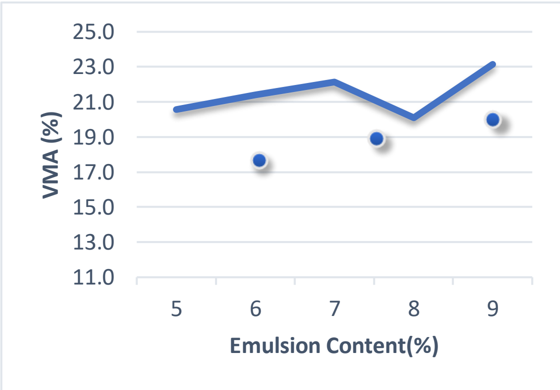


**Figure 4.5 VMA Versus Emulsion Content**

## 4.7 VFB Versus Emulsion Content

The part of the intergranular void space between aggregate particles that is occupied or filled by the effective binder is known as Voids Filled with Asphalt (VFA). VFA is employed to guarantee the appropriate thickness of the asphalt film within the mixture. When VFA is too low, it can result in reduced mix durability, while excessive VFA can lead to mix instability. The required limit as per MS-2 Asphalt Institute method is 70-80 during the design phase. The variation is shown in the Table 4.6. As the emulsion content increases, the voids filled with binder also increases. Here, the obtained VFA was 78%.

**Table 4.6 Variation of VFB with Different Emulsion Content**

| Emulsion Content (%) | VFB (%) |
|---|---|
| 5 | 52.2 |
| 6 | 60.3 |
| 7 | 68.2 |
| 8 | 89.2 |
| 9 | 92.2 |

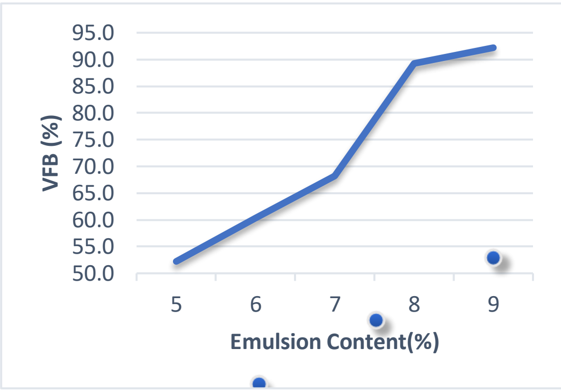


**Figure 4.6 VFB Versus Emulsion Content**

## 4.8 Optimum Emulsion Content (OEC)

After performing the Marshall test, the graph was plotted showing the relationship between various bitumen content and stability, flow, VFB, VMA and specific gravity. The Optimum Emulsion Content was determined by taking average value plotted from the graph of emulsion content versus maximum stability, 4% air void content and maximum unit weight.

**Table 4.7 Calculation of OEC**

| Marshall Properties | Emulsion Content (%) |
|---|---|
| Maximum Stability Value | 8 |
| Maximum Unit Weight | 7.6 |
| 4 % Air Voids | 7.6 |
| Optimum Emulsion Content (%) | **7.73** |

### 4.9 Determination of Mix Properties at Optimum Emulsion Content

The calculated Optimum Emulsion Content was 7.87 %. Further the mix properties were calculated from Figure 4.7, Figure 4.8 and Figure 4.9 Table 4.8 as mentioned below and thus obtained values are tabulated in Table 4.8

**Table 4.8 Value of Mix Properties at OEC**

| Value of Marshall Properties at OEC | | DOR Standard (Section 1300, Table 13.40) |
|---|---|---|
| OEC % | 7.73 | |
| Marshall Stability (KN) | 6.6 | Min 3.43 KN |
| Marshall Flow Value (mm) | 7.2 | Max 8 |
| Air Voids (%) | 3.5 | 10-14 % |
| Marshall Quotient | 0.92 | |

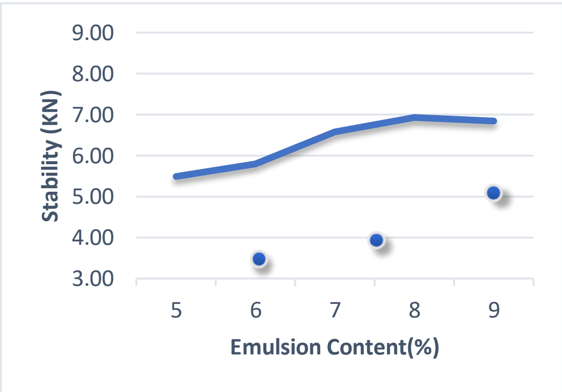


**Figure 4.7Marshall Stability Value at OEC**

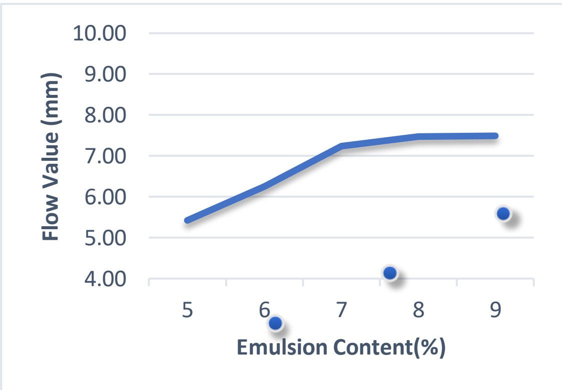


**Figure 4.8 Flow Value at OEC**

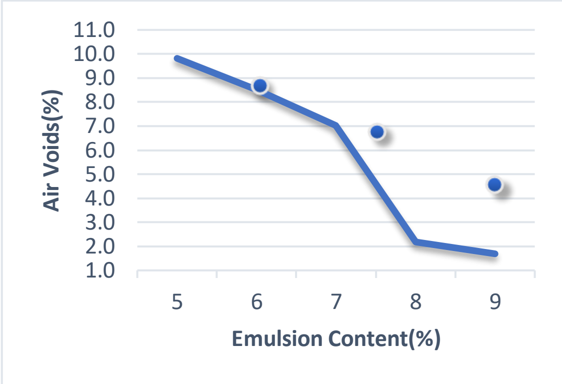


**Figure 4.9 Air Void % at OEC**

Further, the similar procedure was repeated. But this time the conventional filler is added with 1% Ordinary Portland Cement. Once the molds were prepared, Marshall test was done and result was calculated.

### 4.10 Marshall Stability Value Analysis for 1% Cement

The stability value indicates how well an asphalt mixture can resist deformation or rutting when subjected to traffic loads and elevated temperatures. The maximum stability that occurs with varying emulsion content is shown in Table 4.9. The stability value initially increases and then starts to decrease. The maximum stability value at OEC in addition of 1% cement was obtained as 6.8 KN.

**Table 4.9 Variation of Stability Value with Different Emulsion Content**

| Emulsion Content (%) | Stability Value for 1% Cement Content (KN\|) |
|---|---|
| 5 | 5.09 |
| 6 | 5.51 |
| 7 | 6.30 |
| 8 | 6.87 |
| 9 | 6.62 |

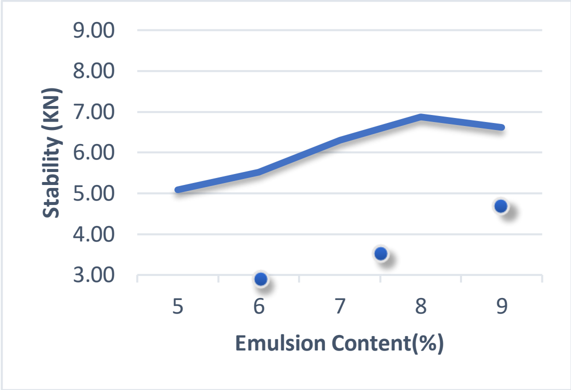


**Figure 4.10 Marshall Stability Versus Emulsion Content**

## 4.11 Flow Value Analysis for 1% Cement

As the emulsion content rises, the flow value of the test specimen also increases. The flow value of the test specimen increases as the emulsion content increases. The variation of flow value with the different emulsion content is as shown in the Figure 4.11. The flow value obtained from the graph for the design mix was 7.3 mm.

**Table 4.10 Variation of Flow Value with Different OEC**

| Emulsion Content (%) | Flow Value 1% Cement Content (mm) |
|---|---|
| 5 | 5.43 |
| 6 | 6.72 |
| 7 | 7.39 |
| 8 | 7.69 |
| 9 | 7.64 |

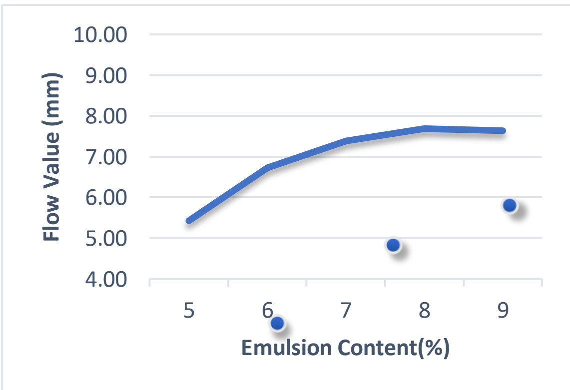

**Figure 4.11 Flow Value Versus Emulsion Content**

## 4.12 Unit Weight Analysis for 1 % Cement

In the Marshall Test, unit weight analysis is typically conducted to assess the density of asphalt concrete samples. This analysis offers crucial insights into the compactness and density of the asphalt concrete mix, which are essential factors for evaluating its durability and load-bearing capacity. The unit weight of the individual specimen was calculated after determining the weights of the specimen. The unit weight of specimen initially increases and the gradually decreases. The maximum unit weight was obtained at 7% Emulsion content.

**Table 4.11 Variation of Unit Content with Different Emulsion Content**

| Emulsion Content (%) | Unit Weight for 1% Cement Content (gm/cm$^3$) |
|---|---|
| 5 | 2.28 |
| 6 | 2.26 |
| 7 | 2.29 |
| 8 | 2.26 |
| 9 | 2.25 |

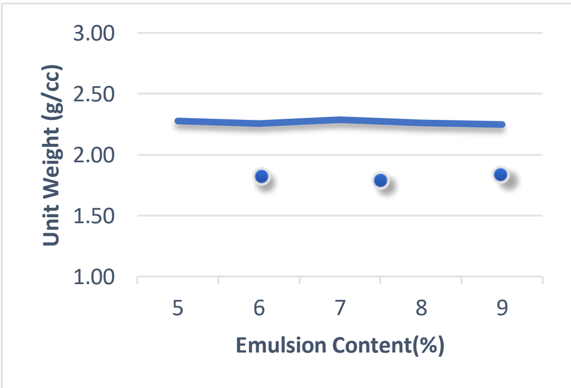


**Figure 4.12 Unit Weight Versus Emulsion Content**

### 4.13 Air Void Analysis

Air void analysis in the Marshall test is a crucial element of assessing and designing asphalt mixtures. Reducing air voids improves the mixture's impermeability, while inadequate air voids can lead to problems such as rutting, shoving, flushing, or bleeding. According to the MS-2 Asphalt Mix Design Methods, the recommended design air void level in a laboratory-compacted sample of Hot Mix Asphalt (HMA) is 4 percent. However, neither the MS-2 Asphalt Mix Design Methods nor SSRB, 2073, provide a specific design air void level for Cold Mix. Therefore, air void analysis is conducted based on Hot Mix design principles. As the emulsion content increases, the air void in the mix decreases. The variation of air void with different amount of emulsion content is as shown in the Table 4.12 As per Asphalt Institute MS-2, the optimum emulsion content is determined at 4% air voids. The air voids obtained at OEC is 4%.

**Table 4.12 Variation of Air Void with Different Emulsion Content**

| Emulsion Content (%) | Air Voids for 1% Cement Content (%) |
|---|---|
| 5 | 7.38 |
| 6 | 6.81 |
| 7 | 4.19 |
| 8 | 4.02 |
| 9 | 3.12 |

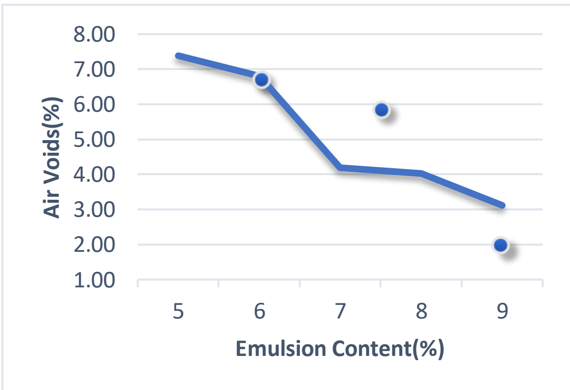


**Figure 4.13 Air Void Versus Emulsion Content**

### 4.14 Voids in Mineral Aggregate (VMA) Analysis

Voids in the Mineral Aggregate (VMA) denote the unoccupied spaces among the aggregate particles within a compacted mixture. It signifies the available area for the bitumen to adequately coat each aggregate particle. Initially, as the emulsion content rises, Voids in Mineral Aggregate decrease, but after a certain point, they begin to increase. When asphalt mixtures have insufficient VMA, they produce thin asphalt coatings, resulting in less resilient asphalt pavements. Initially, the Voids in Mineral Aggregate decrease as the emulsion content increases and then starts to increase. The variation of VMA with increase in emulsion content is sown in Table 4.13. The VMA obtained at OEC was 20.8%.

**Table 4.13 Variation of VMA with Different Emulsion Content**

| Emulsion Content (%) | VMA for 1% Cement Content |
|---|---|
| 5 | 18.41 |
| 6 | 19.95 |
| 7 | 19.75 |
| 8 | 21.61 |
| 9 | 22.83 |

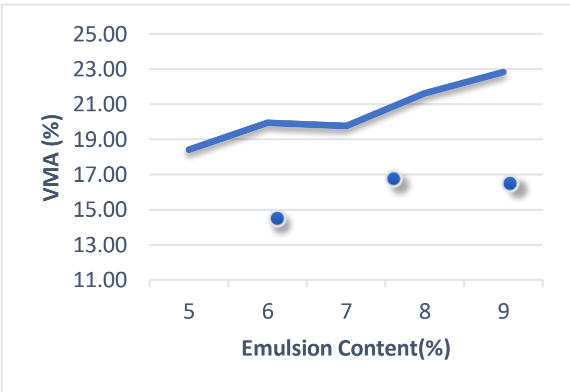


**Figure 4.14 VMA Versus Emulsion Content**

### 4.15 VFB Versus Emulsion Content

Voids Filled with Asphalt (VFB) is the proportion of the open space between aggregate particles that the effective binder occupies. VFA serves to ensure the correct thickness of the asphalt film in the mixture. If VFA is too low, it can reduce the durability of the mix, while excessive VFA can make the mix unstable. According to the MS-2 Asphalt Institute method, the recommended range during the design phase is 70-80 for VFA. As the emulsion content increases, the voids filled with binder also increases. The variation is shown in the Table 4.14. The VFB obtained at OEC was 80.0 %.

**Table 4.14 Variation of VFB with Different Emulsion Content**

| Emulsion Content (%) | VFB for 1% Cement Content (%) |
|---|---|
| 5 | 59.88 |
| 6 | 65.87 |
| 7 | 78.80 |
| 8 | 81.38 |
| 9 | 86.35 |

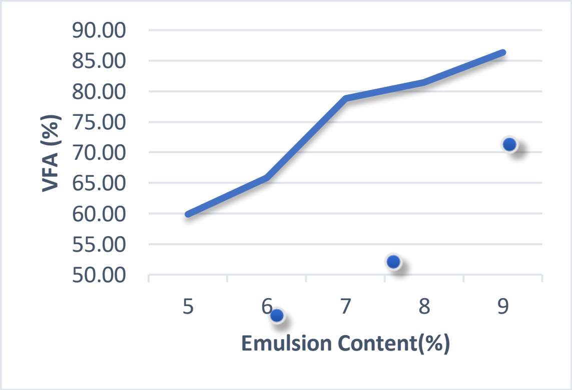


**Figure 4.15 VFB Versus Emulsion Content**

## 4.16 Determination of Optimum Emulsion Content (OEC)

The Marshall test was conducted and the graph was plotted showing the relationship between various emulsion content and stability, flow, VFB, VMA and specific gravity. The Optimum Emulsion Content was determined by taking average value plotted from the graph of emulsion content versus maximum stability, 4% air void content and maximum unit weight.

**Table 4.15 Marshall Properties determining OEC**

| Marshall Properties | Emulsion Content (%) |
|---|---|
| Maximum Stability Value | 8 |
| Maximum Unit Weight | 7 |
| 4 % Air Voids | 8 |
| **Optimum Emulsion Content (%)** | **7.67** |

## 4.17 Determination of Mix Properties at Optimum Emulsion Content

The calculated Optimum Emulsion Content is 7.67 %. Further, the mix properties were calculated from Figure 4.16,Figure 4.17 and Figure 4.18 as mentioned below and thus obtained values are tabulated in Table 4.16.

**Table 4.16 Marshall Properties at OEC on Dry Specimen**

| Value of Marshall Properties at OEC | Values Obtained for 1 % cement content |
|---|---|
| OBC % | 7.67 |
| Marshall Stability (KN) | 6.8 |
| Marshall Flow Value (mm) | 7.5 |
| Air Voids (%) | 4 |
| Marshall Quotient | 0.91 |

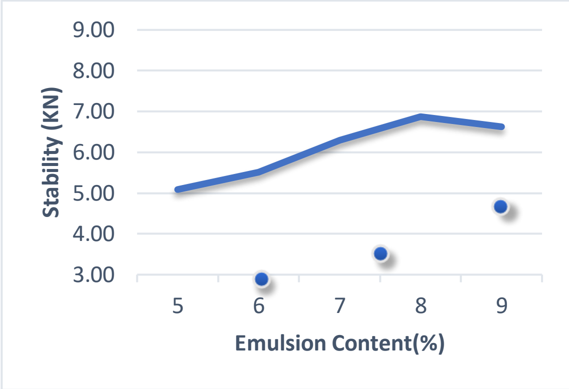


**Figure 4.16 Stability Value at OEC**

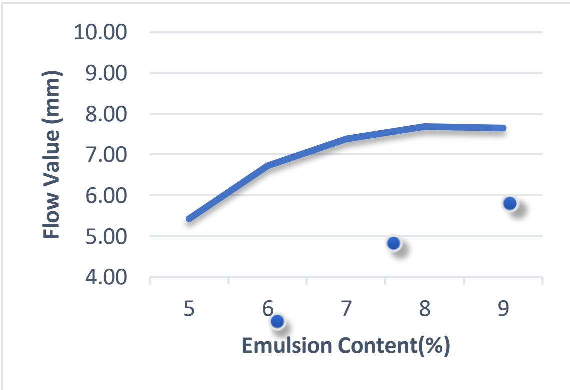


**Figure 4.17 Flow Value at OEC**

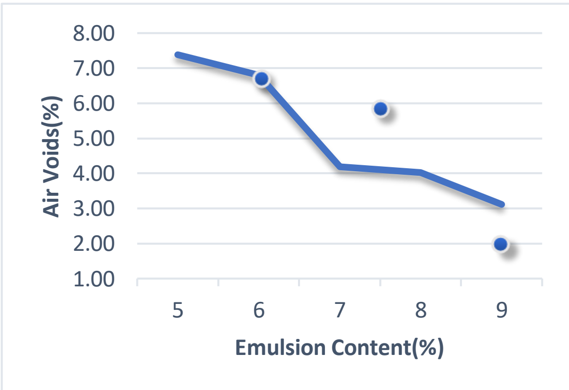


**Figure 4.18 Air Voids at OEC**

Similarly, the further test was conducted by adding 2% cement on conventional filler. After preparing the molds, Marshall test was performed and the result was calculated.

### 4.18 Marshall Stability Value Analysis

The stability value represents the capacity of an asphalt mixture to endure deformation or rutting when exposed to the pressures of traffic loads and elevated temperatures. The maximum stability that occurs with varying emulsion content is shown in Table 4.17. The stability value initially increases and then starts to decrease. The maximum stability value in addition of 2% cement was obtained as 7 KN.

**Table 4.17 Variation of Stability Value with Different Emulsion Content**

| Emulsion Content (%) | Stability Value for 2% Cement Content (KN) |
|---|---|
| 5 | 6.14 |
| 6 | 7.97 |
| 7 | 7.02 |
| 8 | 6.70 |
| 9 | 6.30 |

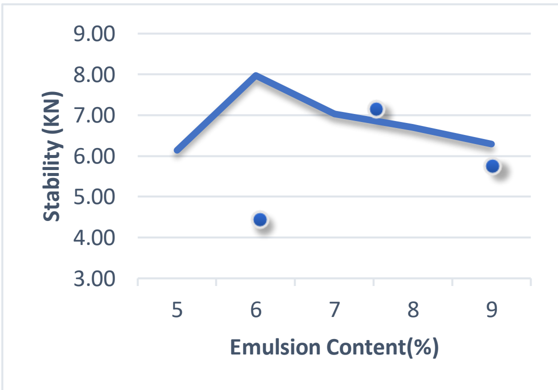


**Figure 4.19 Marshall Stability Versus Emulsion Content**

### 4.19 Flow Value Analysis

The flow value measures the deformation experienced by the test specimen as it is loaded up to its maximum capacity. This deformation in the test specimen rises with an increase in emulsion content. The flow value of the test specimen increases as the emulsion content increases. The variation of flow value with the different emulsion content is as shown in the Figure 4.20. The flow value obtained from the graph for the design mix was 7.5 mm.

**Table 4.18 Variation of Flow Value with Different OEC**

| Emulsion Content (%) | Flow Value for 2% Cement Content |
|---|---|
| 5 | 3.86 |
| 6 | 5.29 |
| 7 | 7.20 |
| 8 | 5.05 |
| 9 | 5.17 |

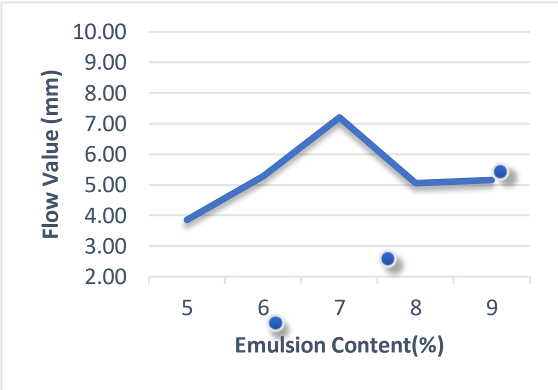


**Figure 4.20 Flow Value Versus Emulsion Content**

## 4.20 Unit Weight Analysis

The evaluation of unit weight is commonly carried out to gauge the density of asphalt concrete samples. This analysis provides crucial information about the compaction and density of the asphalt concrete mixture, serving as a pivotal factor in assessing its durability and load-carrying capacity. The unit weight of the individual specimen was calculated after determining the weights of the specimen. The unit weight of specimen initially increases and the gradually decreases. The maximum unit weight was obtained at 7% emulsion content. The unit weight varied with emulsion content are as shown in Table 4.19.

**Table 4.19 Variation of Unit Content with Different Emulsion Content**

| Emulsion Content (%) | Unit Weight for 2% Cement Content (gm/cm$^3$) |
|---|---|
| 5 | 2.25 |
| 6 | 2.25 |
| 7 | 2.26 |
| 8 | 2.26 |
| 9 | 2.26 |

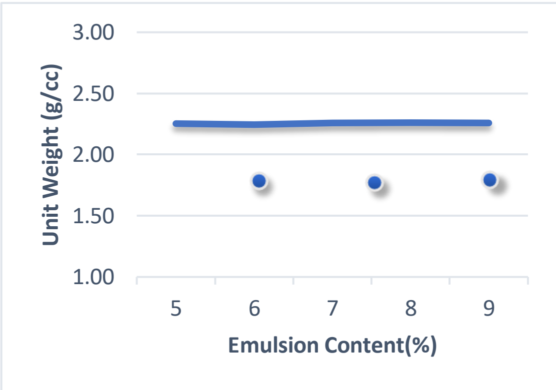


**Figure 4.21 Unit Weight Versus Emulsion Content**

## 4.21 Air Void Analysis

Similarly, the air void analysis was done as in 1% cement content and the design air void level was adopted to be 4%. The variation of air void with different amount of emulsion content is as shown in the Table 4.20. As the emulsion content increases, the air void in the mix decreases. The air voids obtained at OEC is 4%.

**Table 4.20 Variation of Air Void with Different Emulsion Content**

| Emulsion Content (%) | Air Voids Value for 2% cement content (%) |
|---|---|
| 5 | 8.40 |
| 6 | 7.30 |
| 7 | 5.44 |
| 8 | 3.91 |
| 9 | 2.67 |

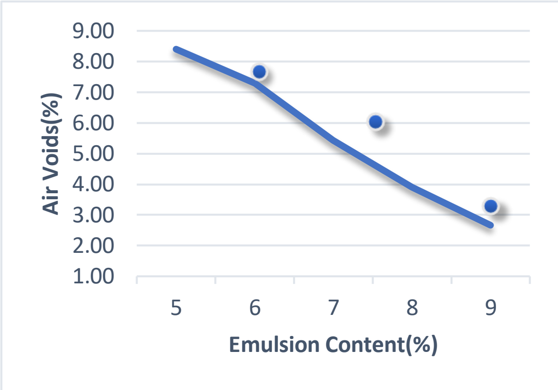


**Figure 4.22 Air Void Versus Emulsion Content**

## 4.22 Voids in Mineral Aggregate (VMA) Analysis

Voids in the Mineral Aggregate (VMA) refer to the empty areas among the aggregate particles within a compacted mixture. It represents the space available for the bitumen to properly cover each aggregate particle. Initially, when the emulsion content increases, Voids in Mineral Aggregate decrease, but beyond a certain point, they start to rise. In cases where asphalt mixtures lack adequate VMA, they generate thin asphalt coatings, leading to less durable asphalt pavements. Initially, the Voids in Mineral Aggregate decrease as the emulsion content increases and then starts to increase. The variation of VMA with increase in emulsion content is sown in Table 4.21. The VMA obtained at OEC was 20.8%.

**Table 4.21 Variation of VMA with Different Emulsion Content**

| Emulsion Content (%) | VMA for 2% cement content (%) |
|---|---|
| 5 | 19.30 |
| 6 | 20.37 |
| 7 | 20.80 |
| 8 | 21.52 |
| 9 | 22.47 |

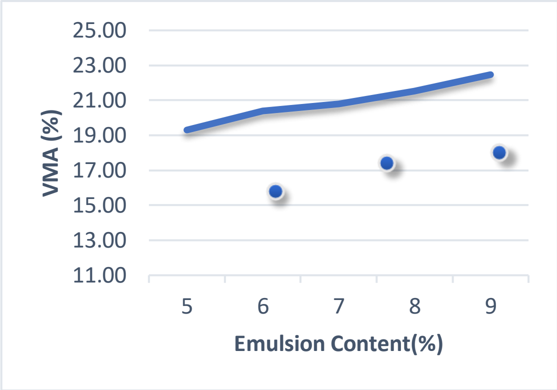


**Figure 4.23 VMA Versus Emulsion Content**

### 4.23 VFB Versus Emulsion Content

Voids Filled with Asphalt (VFA) indicates the part of the empty space between aggregate particles that gets filled by the effective binder. VFA is used to ensure the correct thickness of the asphalt film in the mixture. If VFA falls below the ideal range, it can decrease the durability of the mix, whereas excessive VFA can make the mix less stable. According to the MS-2 Asphalt Institute method, the recommended limit during the design phase is 70-80 for VFA. As the emulsion content increases, the voids filled with binder also increases. The variation is shown in the Table 4.22. The VFA obtained was 79%.

**Table 4.22 Variation of VFB with Different Emulsion Content**

| Emulsion Content (%) | VFB for 2 % cement content (%) |
|---|---|
| 5 | 56.47 |
| 6 | 64.17 |
| 7 | 73.86 |
| 8 | 81.83 |
| 9 | 88.14 |

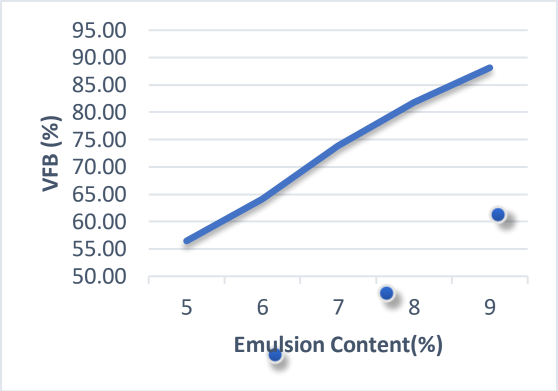


**Figure 4.24 VFB Versus Emulsion Content**

## 4.24 Determination of Optimum Emulsion Content (OEC)

The Marshall test was conducted and the graph was plotted showing the relationship between various emulsion content and stability, flow, VFB, VMA and specific gravity. The Optimum Emulsion Content is determined by taking average value plotted from the graph of emulsion content versus maximum stability, 4% air void content and maximum unit weight.

**Table 4.23 Marshall Properties determining OEC**

| Marshall Properties | Emulsion Content (%) |
|---|---|
| Maximum Stability Value | 8 |
| Maximum Unit Weight | 8 |
| 4 % Air Voids | 6 |
| Optimum Emulsion Content (%) | **7.33** |

## 4.25 Determination of Mix Properties at Optimum Emulsion Content (OEC)

The calculated Optimum Emulsion Content was 7.33 %. Further, the mix properties were calculated from Figure 4.25, Figure 4.26 and Figure 4.27 and as mentioned below and thus obtained values are tabulated in Table 4.24.

**Table 4.24 Marshall Properties at OEC**

| Value of Marshall Properties at OEC | Value obtained at 2% Cement Content |
|---|---|
| OBC % | 7.33 |
| Marshall Stability (KN) | 7 |
| Marshall Flow Value (mm) | 7 |
| Air Voids (%) | 4.2 |
| Marshall Quotient | 1.00 |

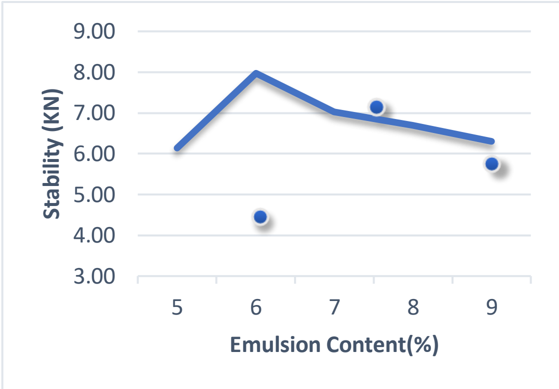


**Figure 4.25 Stability Value at OEC**

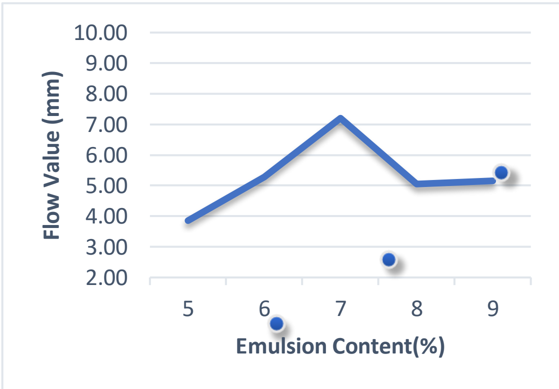


**Figure 4.26 Flow Value at OEC**

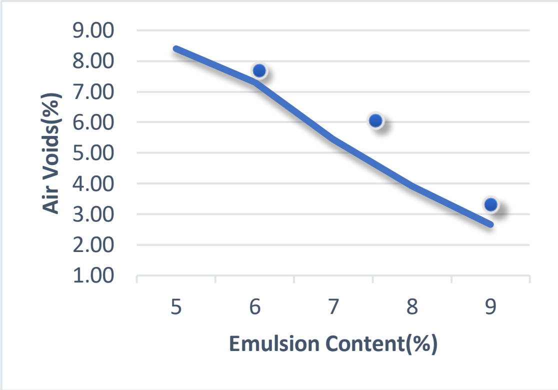


**Figure 4.27 Air Voids at OEC**

### 4.26 Comparison of Mix Properties at Optimum Emulsion Content

From the comparison chart shown in Table 4.25 , it was found that the OEC increases with the increase in cement content. All the Marshall values like stability and flow were within the limit provided by SSRB, 2073 (Section 1300, Table 13.40) except the value of air voids. The air void values were found to be lower than the value provided by SSRB, 2073 for both conventional filler and filler added with cement. The Air Voids remained in minimum range as the value of VFB increased.

**Table 4.25 Comparative Chart Between various Marshall Properties in Addition of OPC at OEC**

| Value of Marshall Properties at OEC | Value Obtained for 0% Cement Content | Value Obtained for 1% Cement Content | Value Obtained for 2% Cement Content | DOR Standard (Sec tion 1300, Table 13.40) |
|---|---|---|---|---|
| OEC % | 7.73 | 7.67 | 7.33 | |
| Marshall Stability (KN) | 6.6 | 6.8 | 7 | Min 3.43 KN |
| Marshall Flow Value (mm) | 7.2 | 7.3 | 7.5 | Max 8 |
| Air Voids (%) | 3.5 | 4 | 4.2 | 10-14 % |
| Marshall Quotient | 0.92 | 0.91 | 1.00 | |

## 4.27 Calculation of Fuel Consumption and Carbon Emission

For plant model Apollo 1000, total plant capacity is 80 tonnes/hr and the fuel required is 7.6MW/h (Catalogue of ANP Batch Asphalt Mixing Plant). As per CDP Technical note, 7.6 MW/h requires 186.732-gallon diesel oil (US). The total fuel required for production of 80 tonnes/hour is 706.85 litres/hr. Following norms for rate analysis of Roads and Bridge Works, 2075(Section 1300, clause 1307), batch mix HMP produce 225 tonnes Bituminous Mix in 6 hours. HMP requires 1884 litres/hour/100 tonnes. Similar calculation was done to determine the total fuel required by Cold Mix Plant (CMP) and the obtained value is as shown in Table 4.26.

**Table 4.26 Fuel Consumption by Hot and Cold Mix Plant**

| S.N. | Description | Quantity |
|---|---|---|
| 1 | Hot Mix Plant (HMP) | 1884 litres/hour/100 tonnes |
| 2 | Cold Mix Plant (CMP) | 942.4 litres/hour/100 tonne |

Detail Calculation is shown in Appendix 6.

## 4.28 Calculation of CO2

As per Federal Register (2010), the total CO2 emitted per gallon of diesel is 10180 gm. The calculation from Table 4.27, it was found that carbon emission rate while producing hot is approximately twice to that of cold mix.

**Table 4.27 Calculation of CO2 Emission**

| S.N. | Description | Quantity |
|---|---|---|
| 1 | Hot Mix Plant (HMP) | 5066603.265 gms of CO2 |
| 2 | Cold Mix Plant (CMP) | 2534377.345 gms of CO2 |

Detail calculation is shown in Appendix 6.

# CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

## 5.1 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 which gives satisfactory value for Marshall stability and Mashall flow. Further findings drawn from the experiment can be concisely summarized as follows:

i. 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.

ii. 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).

iii. 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). This is because cement act as a binder that enhances the cohesion of the mix holding aggregate particles together more effectively resulting the higher stability value.

iv. Marshall flow Value was found to be in range of 7mm to 8 mm and within limit of maximum 8 mm. Cement helps to break emulsion quickly and bitumen droplets coming out from emulsion after adding cement act as a binding material that consequently increases the flow value.

v. The fuel consumed during production of Hot Mix is approximately double to that of Cold Mix.

vi. Also, the amount of carbon emission while producing cold mix is less than that of Hot Mix.

## 5.2 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 conducted 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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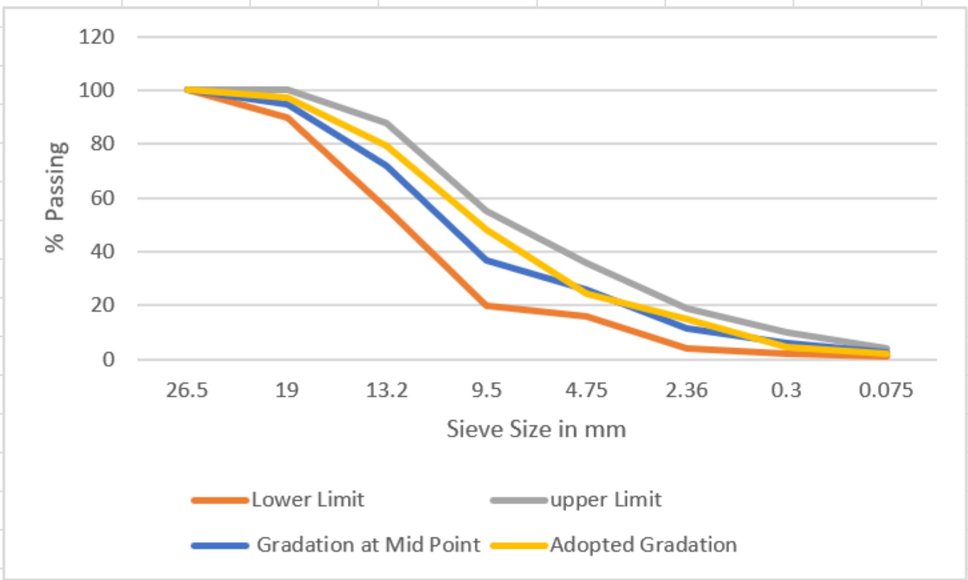
# APPENDIX 1: Sieve Analysis and Proportioning

**Sieve Analysis:**

Total weight taken as sample (gm): 15400

| 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 | | | | |

**Adopted Gradation**



Total weight of conventional filler materials after adding 1% cement

| Sieve Size | Wt. Retained(gm) | Wt. Retained (%) | Wt. Taken (gm) |
|---|---|---|---|
| 26.5 | 0 | 0 | 0 |
| 19 | 435 | 2.89 | 32.85 |
| 13.2 | 2765 | 18.34 | 208.80 |
| 9.5 | 4790 | 31.77 | 361.72 |
| 4.75 | 3680 | 24.41 | 277.89 |
| 2.36 | 1410 | 9.35 | 106.48 |
| 0.3 | 1610 | 10.68 | 121.58 |
| 0.075 | 375 | 2.59 | 28.32 |
| Pan | 335 | 2.22 | 25.30 |
| cement | | | 11.50 |

Total weight of conventional filler materials after adding 2% cement

| Sieve Size | Wt. Retained(gm) | Wt. Retained (%) | Wt. Taken (gm) |
|---|---|---|---|
| 26.5 | 0 | 0 | 0 |
| 19 | 435 | 2.83 | 31.85 |
| 13.2 | 2765 | 17.96 | 202.44 |
| 9.5 | 4790 | 31.12 | 350.69 |
| 4.75 | 3680 | 23.91 | 269.43 |
| 2.36 | 1410 | 9.16 | 103.23 |
| 0.3 | 1610 | 10.46 | 117.87 |
| 0.075 | 375 | 2.44 | 27.16 |
| Pan | 335 | 2.18 | 24.00 |
| Cement | | | 23.0 |

# APPENDIX 2: Aggregate Tests

**Los Angeles Abrasion Test**

Grade – B

Wt. of Aggregate (W1) = 5 kg

Total Revolution= 500 rev

Wt. of Aggregate passing 1.7 mm = 1.13 kg

LAA = 22.69 %

**Aggregate Impact Value Test**

Wt. of Aggregate (W1) = 518.7 gm

Wt. of Aggregate passing 2.36 mm = 63.2 gm

AIV = 13.23%

**Aggregate Crushing Value**

Wt. of Aggregate = 2.55 kg

Wt. of Aggregate passing 2.36 mm = 574.4 gm

ACV = 22.33 %

# APPENDIX 3: Specific Gravity Test of Aggregates

**Specific gravity of Coarse Aggregate**

Wt. of aggregate after oven heating = 501.8 gm

Wt. of SSD sample inside water = 508 gm

Wt. of SSD sample in Air = 313.6 gm

Specific gravity of Coarse Aggregate = 2.66

**Specific gravity of Fine Aggregate**

Wt. of empty bottle = 111.2 gm

Wt. of bottle + Sample = 327.7 gm

Wt. of bottle + sample + Water = 503.9 gm

Wt. of bottle + Water = 368.3 gm

Specific gravity of Fine Aggregate = 2.67

# APPENDIX 4: Emulsion Tests

**Medium Setting Cationic Emulsion (MS - 2)**

**Residue on 600 microns IS Sieve**

Wt. of sample = 2450 gm

Wt. of residue = 542.42 gm

Residue on 600 microns IS Sieve = 0.02%

**Viscosity by Saybolt Furol Viscometer, seconds at 50 °C**

Heat up to 50 °

Viscosity = 72 seconds

**Test on Residue**

**Residue by evaporation**

Wt. of beaker + sample

B1= 347.47 gm

B2 = 344.42 gm

B3 = 342.03 gm

Average (A) = 344.64 gm

Wt. of beaker + sample after heating at oven at 163 °C

B1 = 332.23 gm

B2 = 328.98 gm

B3 = 342.03 gm

Average (B) = 329.39 gm

% residue = 30.5

**Penetration at 25 °C**

Penetration Value 1 = 73 mm

Penetration Value 2 = 74 mm

Penetration Value 3 = 75 mm

Average Penetration Value = 74 mm

**Ductility at 27 °C**

Sample 1 = 63.5 mm

Sample 2 = 100mm

Average Value = 81.75 mm

**Specific Gravity of Emulsion**

Wt. of empty bottle = 33.40 gm

Wt. of bottle + Sample = 52.76 gm

Wt. of bottle + sample + Water = 84.15 gm

Wt. of bottle + Water = 83.78 gm

Specific gravity of Emulsion = 1.019

# APPENDIX 5: Tests on Cement

**Specific gravity of Cement**

Wt. of empty bottle = 14.85 gm

Wt. of bottle + Sample = 24.30 gm

Wt. of bottle + sample + Water = 42.23 gm

Wt. of bottle + Water = 35.23 gm

Specific gravity of Cement = 3.04

**Residue of fineness cement test**

OPC 43 grade

Wt. of dry cement = 100 gm

Wt. retained on 90-micron sieve = 0.96 gm

Wt. Passing on 90-micron sieve = 99.04 gm

Fineness % = 99.04

# APPENDIX 6: Marshall's Test Data and Analysis

## 1. Marshall Test Values for Aggregate Gradation with Conventional Filler

| Bitumen Content (%) | Sample No. | Sample Thickness (mm) | Marshall Test Data for Mix with Conventional Filler | | | | | Flow (Div) | Flow Value (mm) | Mean Flow Value (mm) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Thickness Correction Factor | Proving Ring Reading | Corrected Reading (kN) | Corrected Load(kN) | Mean Stability (kN) | | | |
| 5 | 1 | 73.57 | 0.81 | 225 | 182 | 5.39 | 5.49 | 526 | 5.26 | 5.27 |
| | 2 | 71.33 | 0.83 | 223 | 185 | 5.47 | | 543 | 5.43 | |
| | 3 | 71.90 | 0.83 | 229 | 190 | 5.61 | | 512 | 5.12 | |
| 6 | 4 | 72.00 | 0.82 | 245 | 201 | 5.9 | 5.80 | 639 | 6.39 | 6.25 |
| | 5 | 73.97 | 0.81 | 238 | 193 | 5.7 | | 618 | 6.18 | |
| | 6 | 70.33 | 0.84 | 236 | 198 | 5.8 | | 617 | 6.17 | |
| 7 | 7 | 74.63 | 0.78 | 273 | 213 | 6.26 | 6.58 | 715 | 7.15 | 7.24 |
| | 8 | 71.70 | 0.86 | 278 | 239 | 6.98 | | 736 | 7.36 | |
| | 9 | 72.57 | 0.82 | 269 | 221 | 6.49 | | 722 | 7.22 | |
| 8 | 10 | 73.33 | 0.81 | 287 | 232 | 6.8 | 6.93 | 719 | 7.19 | 7.48 |
| | 11 | 71.97 | 0.83 | 278 | 231 | 6.77 | | 765 | 7.65 | |
| | 12 | 72.03 | 0.83 | 298 | 247 | 7.22 | | 760 | 7.6 | |
| 9 | 13 | 73.00 | 0.81 | 298 | 241 | 7.05 | 6.85 | 727 | 7.27 | 7.49 |
| | 14 | 72.87 | 0.82 | 279 | 229 | 6.7 | | 740 | 7.4 | |
| | 15 | 72.27 | 0.82 | 285 | 234 | 6.8 | | 780 | 7.8 | |

| Bitumen Content (%) | Sample No. | Wt. of dry Specimen in Air(gm) | Wt. of SSD Specimen in Air(gm) | Wt. of Specimen in Water(gm) | Bulk Specific Gravity of Specimen | Average Bulk Specific Gravity | Max Theoretical Specific Gravity |
|---|---|---|---|---|---|---|---|
| 5 | 1 | 1159.3 | 1168.8 | 651.6 | 2.241 | 2.217 | 2.458 |
| | 2 | 1156.9 | 1169.9 | 647.2 | 2.213 | | |
| | 3 | 1153.2 | 1170.9 | 645.5 | 2.195 | | |
| 6 | 4 | 1186.8 | 1210.7 | 671.3 | 2.200 | 2.216 | 2.422 |
| | 5 | 1190.6 | 1214.5 | 675.1 | 2.207 | | |
| | 6 | 1192.6 | 1213.5 | 681.1 | 2.240 | | |
| 7 | 7 | 1185.2 | 1216 | 681.4 | 2.217 | 2.219 | 2.387 |
| | 8 | 1183.8 | 1217 | 680 | 2.204 | | |
| | 9 | 1188.8 | 1216.8 | 685 | 2.235 | | |
| 8 | 10 | 1227.3 | 1225.8 | 688.7 | 2.285 | 2.302 | 2.353 |
| | 11 | 1229.5 | 1224.5 | 690.9 | 2.304 | | |
| | 12 | 1230.7 | 1223.4 | 692.1 | 2.316 | | |
| 9 | 13 | 1218.9 | 1222.9 | 688.7 | 2.282 | 2.281 | 2.281 |
| | 14 | 1219.3 | 1225.6 | 689.1 | 2.273 | | |
| | 15 | 1221.3 | 1224.9 | 691.1 | 2.288 | | |

| Bitumen Content (%) | Sample No. | Percent Air Void | VMA | VFB |
|---|---|---|---|---|
| 5 | 1 | 9.82 | 20.55 | 52.23 |
| | 2 | | | |
| | 3 | | | |
| 6 | 4 | 8.51 | 21.51 | 60.27 |
| | 5 | | | |
| | 6 | | | |
| 7 | 7 | 7.04 | 22.14 | 68.22 |
| | 8 | | | |
| | 9 | | | |
| 8 | 10 | 2.17 | 20.1 | 89.2 |
| | 11 | | | |

| Bitumen Content (%) | Sample No. | Percent Air Void | VMA | VFB |
|---|---|---|---|---|
| 5 | 1 | 9.82 | 20.55 | 52.23 |
| | 2 | | | |
| | 3 | | | |
| | 12 | | | |
| 9 | 13 | 1.69 | 21.69 | 92.22 |
| | 14 | | | |
| | 15 | | | |

2. **Marshall Test Values for Aggregate Gradation with Conventional Filler Adding 1 % Cement**

| Bitumen Content (%) | Sample No. | Sample Thickness (mm) | Marshall Test Data for Mix with Conventional Filler Adding 1% cement | | | | | Flow (Div) | Flow Value (mm) | Mean Flow Value (mm) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Thickness Correction Factor | Proving Ring Reading | Corrected Reading (kN) | Corrected Load(kN) | Mean Stability (kN) | | | |
| 5 | 1 | 78.33 | 0.72 | 225 | 162 | 4.82 | 5.09 | 526 | 5.26 | 5.07 |
| | 2 | 67.27 | 0.82 | 180 | 148 | 4.432 | | 543 | 5.43 | |
| | 3 | 74.23 | 0.93 | 220 | 204 | 6.01 | | 451 | 4.51 | |
| 6 | 4 | 74.53 | 0.78 | 230 | 179 | 6.52 | 5.51 | 639 | 6.39 | 5.91 |
| | 5 | 73.97 | 0.82 | 190 | 156 | 4.65 | | 618 | 6.18 | |
| | 6 | 57.13 | 0.88 | 205 | 181 | 5.36 | | 517 | 5.17 | |
| 7 | 7 | 73.03 | 0.81 | 215 | 174 | 7.22 | 6.76 | 715 | 7.15 | 7.18 |
| | 8 | 71.70 | 0.84 | 216 | 181 | 6.66 | | 636 | 6.36 | |
| | 9 | 78.33 | 0.86 | 212 | 182 | 6.4 | | 802 | 8.02 | |
| 8 | 10 | 72.20 | 0.82 | 300 | 246 | 8.35 | 7.34 | 719 | 7.19 | 5.66 |
| | 11 | 74.30 | 0.77 | 271 | 209 | 6.15 | | 664 | 6.64 | |
| | 12 | 73.83 | 0.86 | 290 | 249 | 7.53 | | 316 | 3.16 | |
| 9 | 13 | 74.90 | 0.79 | 345 | 273 | 7.95 | 6.95 | 727 | 7.27 | 6.79 |
| | 14 | 73.90 | 0.78 | 265 | 207 | 6.08 | | 963 | 9.63 | |
| | 15 | 74.27 | 0.84 | 277 | 233 | 6.83 | | 348 | 3.48 | |

| Bitumen Content (%) | Sample No. | Wt. of dry Specimen in Air(gm) | Wt. of SSD Specimen in Air(gm) | Wt. of Specimen in Water(gm) | Bulk Specific Gravity of Specimen | Average Bulk Specific Gravity | Max Theoretical Specific Gravity |
|---|---|---|---|---|---|---|---|
| 5 | 1 | 1159.3 | 1175.9 | 668.6 | 2.285 | 2.276 | 2.458 |
| | 2 | 1156.9 | 1178.3 | 668.8 | 2.271 | | |
| | 3 | 1153.2 | 1175.8 | 668.5 | 2.273 | | |
| 6 | 4 | 1199.8 | 1209.5 | 678.8 | 2.261 | 2.257 | 2.422 |
| | 5 | 1198.6 | 1207.6 | 679.9 | 2.271 | | |
| | 6 | 1199 | 1215.9 | 680.3 | 2.239 | | |
| 7 | 7 | 1194.7 | 1216.9 | 689.1 | 2.264 | 2.287 | 2.387 |
| | 8 | 1195.5 | 1209.6 | 689.7 | 2.299 | | |
| | 9 | 1195.1 | 1210.2 | 690.1 | 2.298 | | |
| 8 | 10 | 1208.7 | 1211.4 | 674.8 | 2.253 | 2.258 | 2.353 |
| | 11 | 1208.2 | 1210.3 | 675.5 | 2.259 | | |
| | 12 | 1207.4 | 1209.6 | 676.1 | 2.263 | | |
| 9 | 13 | 1249.5 | 1253.6 | 694.5 | 2.235 | 2.248 | 2.281 |
| | 14 | 1250.2 | 1254.3 | 695.1 | 2.236 | | |
| | 15 | 1250.5 | 1245.3 | 695 | 2.272 | | |

| Bitumen Content (%) | Sample No. | Percent Air Void | VMA | VFB |
|---|---|---|---|---|
| 5 | 1 | 7.38 | 18.41 | 59.88 |
| | 2 | | | |
| | 3 | | | |
| 6 | 4 | 6.81 | 19.95 | 65.87 |
| | 5 | | | |
| | 6 | | | |
| 7 | 7 | 4.19 | 19.75 | 78.8 |
| | 8 | | | |
| | 9 | | | |
| 8 | 10 | 4.02 | 21.61 | 81.38 |
| | 11 | | | |
| | 12 | | | |
| 9 | 13 | 3.12 | 22.83 | 86.35 |
| | 14 | | | |

| Bitumen Content (%) | Sample No. | Percent Air Void | VMA | VFB |
|---|---|---|---|---|
| 5 | 1 | 7.38 | 18.41 | 59.88 |
| | 2 | | | |
| | 3 | | | |
| | 15 | | | |

3. **Marshall Test Values for Aggregate Gradation with Conventional Filler Adding 1 % Cement**

| Bitumen Content (%) | Sample No. | Sample Thickness (mm) | Marshall Test Data for Mix with Conventional Filler Adding 2% Cement | | | | | Flow (Div) | Flow Value (mm) | Mean Flow Value (mm) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Thickness Correction Factor | Proving Ring Reading | Corrected Reading (kN) | Corrected Load(kN) | Mean Stability (kN) | | | |
| 5 | 1 | 72.00 | 0.82 | 250 | 205 | 6.04 | 6.14 | 327 | 3.27 | 3.86 |
| | 2 | 69.27 | 0.89 | 267 | 238 | 6.97 | | 420 | 4.2 | |
| | 3 | 71.90 | 0.83 | 220 | 183 | 5.41 | | 410 | 4.1 | |
| 6 | 4 | 71.70 | 0.83 | 330 | 274 | 8.1 | 8.10 | 560 | 5.6 | 5.29 |
| | 5 | 71.98 | 0.83 | 340 | 282 | 8.32 | | 510 | 5.1 | |
| | 6 | 68.80 | 0.88 | 300 | 265 | 7.87 | | 517 | 5.17 | |
| 7 | 7 | 73.00 | 0.86 | 290 | 249 | 7.28 | 7.02 | 763 | 7.63 | 7.20 |
| | 8 | 71.70 | 0.83 | 295 | 245 | 7.16 | | 696 | 6.96 | |
| | 9 | 74.30 | 0.78 | 290 | 226 | 6.63 | | 702 | 7.02 | |
| 8 | 10 | 70.77 | 0.85 | 270 | 230 | 6.7 | 6.70 | 500 | 5 | 5.05 |
| | 11 | 72.63 | 0.82 | 280 | 230 | 6.7 | | 524 | 5.24 | |
| | 12 | 72.83 | 0.82 | 280 | 230 | 6.7 | | 490 | 4.9 | |
| 9 | 13 | 75.27 | 0.77 | 280 | 216 | 6.3 | 6.30 | 530 | 5.3 | 5.17 |
| | 14 | 73.57 | 0.79 | 270 | 213 | 6.2 | | 540 | 5.4 | |
| | 15 | 73.93 | 0.80 | 275 | 220 | 6.4 | | 480 | 4.8 | |

| Bitumen | Sample No. | Wt. of dry Specim | Wt. of SSD | Wt. of Specimen | Bulk Specific Gravity | Average Bulk | Max Theoretical |
|---|---|---|---|---|---|---|---|

| Conte nt (%) | | en in Air(gm ) | Specimen in Air(gm) | in Water (gm) | of Specime n | Specif ic Gravi ty | Specifi c Gravit y |
|---|---|---|---|---|---|---|---|
| 5 | 1 | 1158.9 | 1179.3 | 662.8 | 2.244 | 2.251 | 2.458 |
| | 2 | 1154.6 | 1179.6 | 665 | 2.244 | | |
| | 3 | 1156.6 | 1178.3 | 668 | 2.267 | | |
| 6 | 4 | 1201.3 | 1210.3 | 664.3 | 2.200 | 2.245 | 2.422 |
| | 5 | 1204.3 | 1209.9 | 678.2 | 2.265 | | |
| | 6 | 1205.6 | 1210.5 | 679.4 | 2.270 | | |
| 7 | 7 | 1230 | 1236.8 | 695 | 2.270 | 2.257 | 2.387 |
| | 8 | 1233.4 | 1239.6 | 694 | 2.261 | | |
| | 9 | 1235 | 1240.5 | 689.3 | 2.241 | | |
| 8 | 10 | 1233.5 | 1238.7 | 694.3 | 2.266 | 2.261 | 2.353 |
| | 11 | 1234.6 | 1237.5 | 691.2 | 2.260 | | |
| | 12 | 1234.59 | 1239.3 | 692.3 | 2.257 | | |
| 9 | 13 | 1240.69 | 1246.3 | 698 | 2.263 | 2.258 | 2.32 |
| | 14 | 1242.36 | 1247.6 | 696 | 2.252 | | |
| | 15 | 1245.69 | 1249.5 | 698.12 | 2.259 | | |

| Bitumen Content (%) | Sample No. | Percent Air Void | VMA | VFB |
|---|---|---|---|---|
| 5 | 1 | 8.4 | 19.3 | 56.47 |
| | 2 | | | |
| | 3 | | | |
| 6 | 4 | 7.3 | 20.37 | 64.17 |
| | 5 | | | |
| | 6 | | | |
| 7 | 7 | 5.44 | 20.8 | 73.86 |
| | 8 | | | |
| | 9 | | | |
| 8 | 10 | 3.91 | 21.52 | 81.83 |
| | 11 | | | |
| | 12 | | | |
| 9 | 13 | 2.67 | 22.47 | 84.14 |
| | 14 | | | |

| Bitumen Content (%) | Sample No. | Percent Air Void | VMA | VFB |
|---|---|---|---|---|
| 5 | 1 | 8.4 | 19.3 | 56.47 |
| | 2 | | | |
| | 3 | | | |
| | 15 | | | |

# APPENDIX 6: Fuel Consumption and Carbon Emission Calculation

**Calculation of Fuel Consumption**

| | | | |
|---|---|---|---|
| 1 | Plant Capacity | 80 tonnes/hr | For Plant Model Apollo 1000 Catalogue of ANP Batch Asphalt Mixing Plant |
| 2 | Fuel Required | 7.6 MW/h | For Plant Model Apollo 1000 Catalogue of ANP Batch Asphalt Mixing Plant |
| 3 | 7.6 MW/h | 186.732-gallon disel oil (US) | As per CDP Technical Note |
| 4 | 1 Gallon diesel oil | 3.7854 litres | |
| 5 | Total fuel for the production of 80 tonnes/ h | 706.85 litres/h | |
| 6 | Batch mix HMP produce 225 tonne Bituminous Mix in 6 hours | | As per Norms for Rate Analysis of Road and Bridge works, 2075 (section 1300, clause 1307). |
| 7 | HMP requires | 18.84933333 litres/hour/100 tonne | |
| 8 | HMP requires 18.84 litres/hour/tonne | | |
| 9 | HMP requires 1884 litres/hour/100 tonne | | |
| 10 | Drum Mix Plant Produce 450 tonne Bituminous Mix in CMP 6 hours | | As per Norms for Rate Analysis of Road and Bridge works, 2075 (section 1300, clause 1313). |
| 11 | CMP requires | 9.424666667 litres/hour/100 tonne | |
| 12 | CMP requires 9.424 litres/hour/tonne | | |
| 13 | CMP requires 942.4 litres/hour/100 tonne | | |

**Calculation of Carbon emission**

| | | | |
|---|---|---|---|
| 1 | 1 gallon of diesel produce | 10180 gm of CO2 | |

| | | | |
|---|---|---|---|
| 2 | 1 gallon of diesel contains | 3.7854 litres | |
| 3 | 3.7854 litres of diesel produce | 10180 gm of CO2 | |
| 4 | 1 litre of diesel = | 2689.279865 | gms of CO2 |
| 5 | For Hot Mix Plant | | |
| 6 | HMP requires 1884 litres/hour/100 tonne | | |
| 7 | Total Carbon emission while producing 100 tonne mix | 5066603.265 | gms of CO2 |
| 8 | For Cold Mix Plant | | |
| 9 | CMP requires 942.4 litres/hour/100 tonne | | |
| 10 | Total Carbon emission while producing 100 tonne mix | 2534377.345 | gms of CO2 |