PERFORMANCE ASSESSMENT OF EMULSIFIED COLD MIX ASPHALT FOR LOW TRAFFIC ROADS IN ETHIOPIA

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ABSTRACT

In recent years, there has been a growing shift towards the utilization of cold mix asphalt with bitumen emulsion as an alternative method for pavement maintenance and construction. This trend is driven by its environmentally sustainable attributes, which contribute to a reduced carbon footprint compared to hot-mix asphalt applications.

The primary objective of this study was to assess performance of cold mix asphalt under laboratory setting, where varying proportions of emulsified binder, aggregate, and additives were examined using the Marshall method of mix design.

The investigation involved, preparation of Marshall samples with proportions of 6% to 10% cationic slow setting emulsion (CSS-1h), 0% to 3% rock filler, and 0% to 3% ordinary Portland cement and aggregates.

The results of this study indicated that additions of cement and rock filler can bring significant changes in the engineering characteristics of the cold mix, impacting parameters such as stability, flow rate, and density. Notably, mixtures containing 3% rock filler and no cement filler demonstrated inferior performance compared to other combinations. Conversely, mixtures with 0% rock filler and 3% cement filler exhibited superior results. The findings suggest that the most optimal outcomes were achieved when employing a combination of 2% rock filler and 1% cement filler.

1. INTRODUCTION

Enhancing rural communities' transportation options is essential for fostering rural development, expanding access to human development services like health and education, facilitating the integration of disparate societal groups, creating better job opportunities, and spurring economic growth in order to reduce poverty. According to the Ministry of Urban and Infrastructure Development's assessment report (2022) on the 24-year road sector development plan of the Ethiopian Roads Administration, in 2021, 33.1% of the land was located more than 5 kilometers from all-weather roads. By way of comparation, the proportion of area more than 5 km from all-weather road was 79% in 1997 (World Bank 2018). The 2022 report also indicated that as of the end of 2021, there were roughly 155, 830 kilometers of roads in the nation. It was demonstrated that of the entire road networks, 16, 225 km were paved and 139,605 km were unpaved. The national and local governments through various initiatives such as universal rural road access program and road sector development plan to improve road standards and their accessibility to rural communities, still about 60 percent of village people of the country are not connected by all-weather roads.

In Ethiopia, hot mix asphalt is the predominant method for constructing roads, accounting for approximately 80% to 90% of all all-weather roads in the country. This technique ensures a smooth and enhanced driving experience for passengers. However, because mixing and compaction must be done at high temperatures, usually between 135°C and 180°C, the manufacture needs a large quantity of energy (Choudhary et al., 2012; Fang et al., 2016; Calabi-Floody et al., 2020). Emulsified cold mix asphalt is a combination made by bitumen emulsion, aggregates, and filler at room temperature (10°C-30°C). This method can yield energy savings of approximately 95% when compared to the manufacturing of hot mix asphalt. Significant air pollution is also caused by the dust and pollutants from the heated aggregate and mixture at such high temperatures. As a result, scientists are working to develop less energy-intensive and emission-producing ways of producing asphalt materials while maintaining a quality comparable to that of hot mix asphalt. Its nature gives several benefits over conventional hot mix asphalt, which makes it a desirable substitute for a variety of paving applications, from full-scale pavement construction to preventive maintenance and repair (Ling et al., 2013). Since no heating is needed during manufacturing, its mixtures offer a cost-effective, energy-efficient, and sustainable alternative to traditional hot mixtures (Dulaimi et al., 2015). Moreover, it has the ability to be stored and has a longer working life, meaning it can be transported longer distances and placed in locations generally inaccessible or impractical for more traditional methods.

Despite its benefits, cold mix technology has certain performance-related problems that need to be addressed before being used in the field for road construction. One of the issues is related to the mixture's moisture content, which remains in the wet aggregate, making it susceptible to moisture damage. Additionally, water in the asphalt emulsion causes damage to the aggregate in the form of stripping because it could break the bond between the aggregate and the asphalt binder residue (Ling et al., 2013). Nevertheless, the poor performance of the cold mix asphalt can be improved by incorporating fibers, chemicals, and additives (such as lime, cement, or fly ash). According to Fang et al. (2016), the inadequate early performance of emulsified cold mix asphalt can be improved by adding ordinary Portland cement (OPC). It was observed that incorporating 1% to 2% of OPC by mass significantly enhances the early mechanical properties of the mixtures. The fully cured material can achieve mechanical properties comparable to those of equivalent hot mix asphalt. Additionally, this modification substantially improves early stiffness, reduces permanent deformation, and increases the durability of the mixtures (Dulaimi et al., 2015).

1.1 Aim of the Study

In countries like Ethiopia, the research and application of emulsified cold mix technology are lagging. This study aims to investigate whether incorporating various amounts of cement and local rock filler into mix combinations can enhance the performance of cold mix asphalt, making it a viable alternative for pavement maintenance and construction.

1.2 Problem Statement

Hot mix asphalt is a widely used technology in the road construction industry due to its efficiency in building durable roads. However, this technology presents several disadvantages, including high costs, significant environmental impact, and complex construction procedures. In contrast, emulsified cold mix asphalt requires significantly less energy to produce and emits minimal to no pollutants during manufacturing. Despite these advantages, emulsified cold mix asphalt receives less attention due to its perceived inferior performance compared to hot mix asphalt. Brown and Needham (2000) and Dash (2013) highlight that various factors, such as binder grade, void content, curing conditions, curing duration, and additives like cement, influence the mechanical properties of cold mixes. Dash (2013) suggests that the poor performance of emulsified cold mix can be improved by incorporating additives and chemicals. However, Thanaya et al. (2009) point out issues such as high air-void content in compacted mixes and weak early-life strength, caused by pre-wetting water inhibiting proper compaction. This study aims to address these issues by examining whether adding different amounts of cement and rock filler to mix combinations can enhance the performance of emulsified cold mix asphalt, making it a viable alternative for pavement maintenance and construction.

1.3 Scope of Paper

It is evident in developing nations such as Ethiopia that emulsified cold mix technology is falling behind in both research and application domain. The selection of this technology as the current study focus is primarily motivated by this. In order to minimize petroleum solvent use in road construction, minimize heating, reduce air pollution, coat damp aggregate surfaces to reduce the amount of fuel needed to heat and dry them, use cold bituminous materials at remote sites, and protect the health of construction workers, emulsified cold mix asphalts will be the subject of research.

2. MATERIALS AND METHOD

The mixture for the laboratory experiment was created by the components into predetermined amounts. Five distinct mixtures with varying amounts of emulsified bitumen, cement, and rock filler were included in the experimental investigation. To determine the best mix design for the project, assessments of various mixes were carried out in the lab. The mixture contained 6%, 7%, 8%, 9%, and 10% emulsified bitumen. Similarly, filler and additives as cement at 0%, 1%, 2%, 2.5%, 3% and rock filler at 3%,2%,1%,0.5%,0%, were utilized. An assessment was conducted on the Marshall stability, Marshall flow value, air void, and density of the compacted mix. For every blend, the ideal emulsified bitumen content was determined.

2.1 Materials

2.1.1 Aggregate

2.1.1.1 Aggregate Gradation and Blending

The emulsified cold mix design utilized aggregates that were gathered from the Awash Crusher Site, which is situated approximately 65 kilometers Southwest of Addis Ababa. Table 1 illustrates the proportion of 45% to 55% that the coarse and fine aggregates were blended, respectively.

2.1.1.2 Aggregate Physical Property

Table 2 displays the findings of the physical property analysis of aggregates carried out at the Road Research Centre laboratory. As can be seen, they all fulfill the requirements of Ethiopian Roads Administration Low Volume Road Design Manual (Ethiopian Roads Authority 2016).

Table 1: Job aggregate gradation and blending

Sieve size (mm)	Coarse Aggregate (%)	Fine Aggregate (%)	Coarse to Fine (%)(45:55)	ERA Specification limit[1] (%)
14	100.00	100.00	100	100
10	95.96	99.62	98	85-100
6.3	31.05	94.41	66	62-78
5	14.992	92.56	58	46-60
2	0.81	59.63	33	28-40
1.180	0.60	42.93	24	16-26
0.425	0.40	18.82	11	7-13
0.300	0.35	12.34	7	5-10
0.150	0.23	5.30	4	2-6
0.075	0.10	5.45	3	1-3

[1] Ethiopian Roads Authority (2002)

Table 2: Physical properties of job mix aggregates

Id	Type of Tests	Laboratory Results (%)	ERA specification Limit (%)
1	Aggregate Impact Value	8	<25
2	Aggregate Crushing Value	13.7	<35
3	Loss Angles Abrasion	14	<35
4	Water Absorption	1.25	<2
5	Flakiness Index	31	<35

2.1.2 Filler

To provide early life stiffness and strength and to control the emulsion breaking process, filler material was added to the mixture. The formulation of the filler material proportions in the mix design was based on studies of emulsified cold mix asphalts by Oruc et al. (2007), Thanaya (2007), Dulaimi et al. (2015), and Fang et al. (2016). Consequently, this investigation utilized 0%, 1%, 2%, 2.5%, and 3% of OPC, and 3%, 2%, 1%, 0.5%, and 0% of rock filler.

2.1.3 Bitumen Emulsion

The cationic slow setting bitumen emulsion (CSS-1h) was utilized in this study due to its enhanced mixing stability with aggregate compositions. Specifically, the mixture included fine aggregates passing a 2.36 mm sieve at over 20% (33% of the total aggregate) and fines passing a 75µm sieve at 3% (3% of the total aggregate).

2.2 Method

2.2.1 Production of Mixtures

Before producing mixtures, the residual asphalt content was initially estimated using the formula from the (Asphalt Institute, 1989).

$$P = (0.05A+0.1B + 0.5C)\ (0.7) \qquad (1)$$

Where:
P=% of initial residual asphalt content.

Referring to Table 1,
A= % coarse aggregates (retain on 2.36 mm) = 62%;
B = % fine aggregates (passing 2.36 mm retain on 0.075mm) = 35%;
C=% of filler = 3%.

It was found that, P = 5.67%

The initial emulsion content (IEC) was calculated as

$$IEC = (P/X)x100 \tag{2}$$

Where:

IEC= Initial Emulsion Content;

X =% of asphalt content of the emulsion (65%);

It was found that, IEC was obtained to be 8.7%.

The aggregates were proportioned in accordance with the intended aggregate grading specification of emulsified cold mix asphalt in order to produce the mixtures. After that, the aggregates were dried, evenly mixed, and pre-wetted with water. After adding the necessary amount of asphalt emulsion, it was mixed further until the emulsion evenly coated the aggregates.

2.2.2 Mix Proportion

The design proportion of cement, rock filler, emulsified asphalt, and designed gradation for preparation of samples to analyze stability and volumetric property of the compacted mix shown in Table 3 below. The amount of cement and rock filler used instead of the percentage of three percent of blended aggregate in the mix.

Table 3: Proportion of cement, rock filler and emulsified bitumen

Sieve size (mm)	Percentage Passing Blended aggregate	Ordinary Portland cement	Rock Filler	Emulsified Bitumen
14	100	0%,1%,2%,2.5%,3%	3%,2%,1%,0.5%,0%	6%,7%,8%,9%,10%
10	98			
6.3	66			
5	58			
2	33			
1.18	24			
0.425	11			
0.300	7			
0.150	4			
0.075	3			

2.2.3 Coating and Determination of Optimum Pre-Wetting Water Content

The coating test is carried out by mixing 500 grams of dry aggregates and filler with a varied amount of water at 1%, 2%, 3%, and 4% by dry weight of aggregate and mixing by hand until uniformly dispersed (Asphalt Institute (AI) and Asphalt Emulsion Manufacturers Association (AEMA), 2008). The optimum pre-wetting water content that gives the best asphalt coating on the mineral aggregates at each percentage of trial emulsified bitumen, in which the mixture was neither too sloppy nor too stiff, was determined. 2% was the ideal amount of pre-wetting water content for this experiment, and the entire experimental mix was made up of this percentage of water content by weight of dry aggregate and filler

2.2.4 Aggregate and Pre-Wetting Water Mixing

For ten seconds, manually mix the design aggregate with 2% water by weight of dry aggregate. This was finished right before the emulsion was added and mixed (AI and AEMA, 2008). For a maximum of sixty seconds, or until enough emulsion dispersion had occurred or the mixture's color had changed from black to brown, the mixture was evenly stirred.

2.2.5 Compaction

The batch was placed into the cleaned specimen mould, and the mixture was vigorously spaded with a spatula. Applying 50 blows with the compaction hammer at a free fall of 1457 mm, the mould assembly was placed on the compaction pedestal in the mould holder (AI and AEMA, 2008). The moulded specimen was reversed and its base plate and collar were removed. It was then put back together and the reversed specimen was subjected to 50 compaction blows. Place the mould containing the compacted specimen on a perforated shelf in a forced draft oven set at 60°C for 48 hours after removing the base plate, collar, and paper disc as shown at Figure 1. This procedure is used to remove the excess water in the mixture.

Figure 1: Compacted specimen in 60^{o}C oven

The mold containing the compacted specimen removed from the oven still at 60^{o}C and applied a static load of 178 kilo-Newton by the double plunger method as illustrated at figure 2 where a free-fitting plunger is placed at both the bottom and top of the specimen in the mold. This load made the compacted sample to condense more and remove some water from the compacted specimen. Applied the load at a rate to give about 1.3mm/minute of compression and maintain the full load for one minute and then released.

Figure 2: Compacted specimen applied a 178KN static load

The compacted specimen allowed cooling in the mold for a minimum of one hour prior to extracting the specimen for Marshall testing as shown at Figure 3 and then stability and flow value was conducting at the failure point.

Figure 3: Marshall Stability and flow

3. RESULTS AND DISCUSSION

Specimens with a moisture content of 2% were made by combining different proportions of job aggregate, ordinary Portland cement, rock filler, and emulsified bitumen. The bulk density, air void, flow value, and Marshall stability of each cement and rock filler combination containing a varying amount of emulsified bitumen were determined. The laboratory testing results from each proportion were analyzed to determine the optimal cement, rock filler, and emulsified bitumen to predicted for realistic percentages. The laboratory experimental findings for each fraction of parameters are shown in figures 4 to 8.

3.1 Mixture at 3% Rock Filler and 0% Cement

As the proportion of emulsified bitumen in the mix increased, Marshall stability, flow rate, and percent air void mix all reduced whereas, the density of the total mixture increased as illustrated in Figure 4.

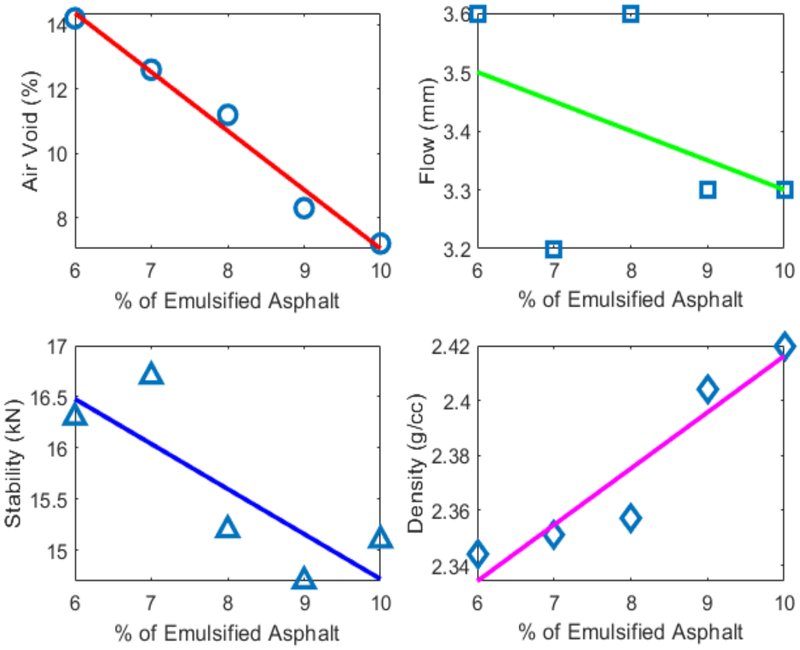

Figure 4: Mix performance at 3% rock filler and 0% cement

3.2 Mixture at 2% Rock Filler and 1% Cement

Figure 5 illustrates how the percentage of air void in the mix dropped as the amount of emulsified bitumen rose and how mixes stability and density increased and minimal change in the flow rate.

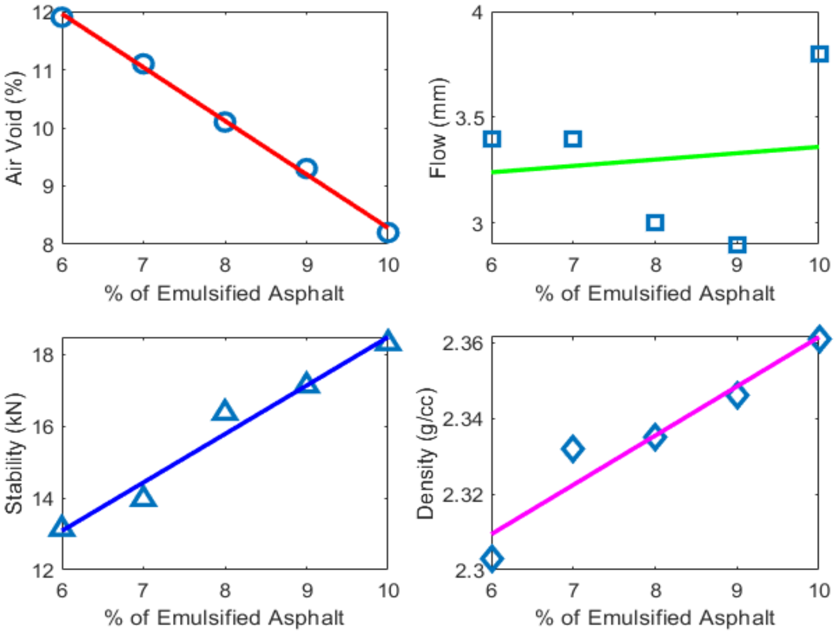

Figure 5: Mix performance at 2% rock filler and 1% cement

3.3 Mixture at 1% Rock Filler and 2% Cement

As the proportion of emulsified bitumen increased the percentage of air void and flow rate in the mix dropped, while the density and Marshall stability of the mix improved, as illustrated in Figure 6.

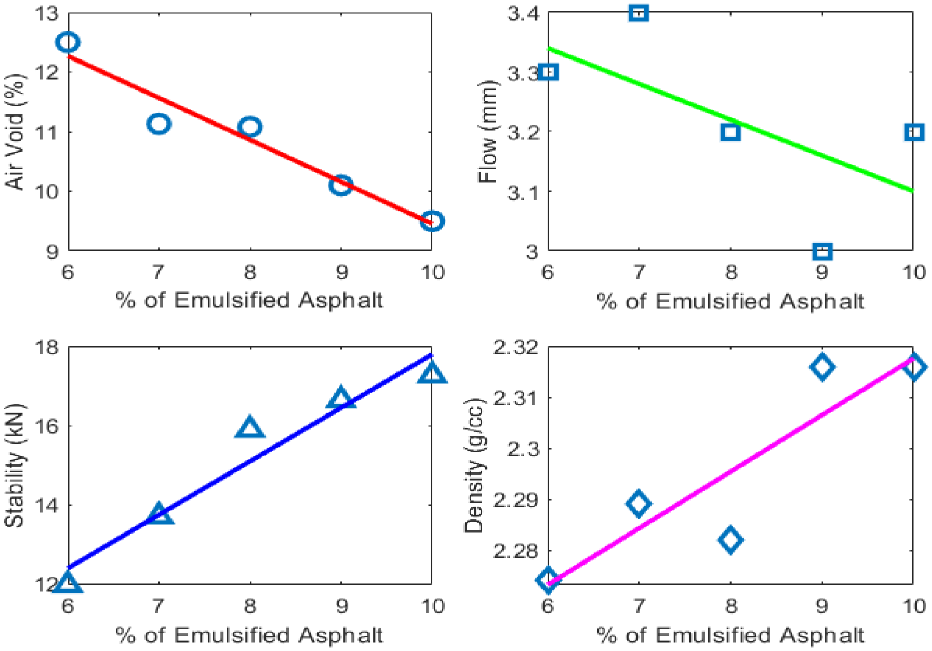

Figure 6: Mix performance at 1% rock filler and 2% cement

3.4 Mixture at 0.5% Rock Filler and 2.5% Cement

Percentage air void decreased and flow rate increased and then decreased as the percentage of emulsified bitumen increased while, stability and density increased as shown at Figure 7.

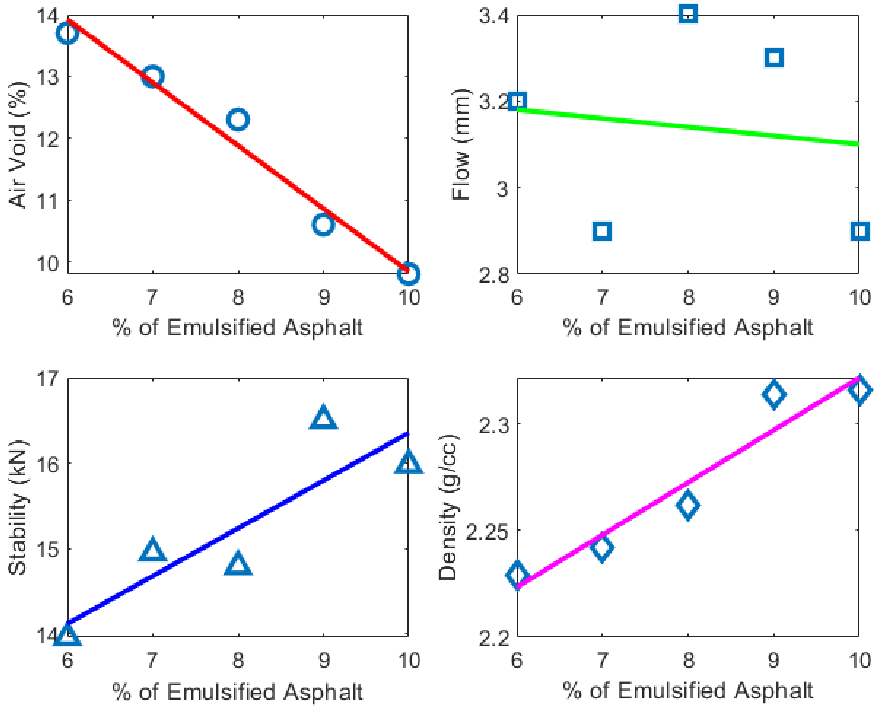

Figure 7: Mix performance at 0.5% rock filler and 2.5% cement

3.5 Mixture at 0% Rock Filler and 3% Cement

As the percentage of emulsified bitumen increased, the percentage of air void and flow rate dropped, but the percentage of stability and density increased, as illustrated in Figure 8.

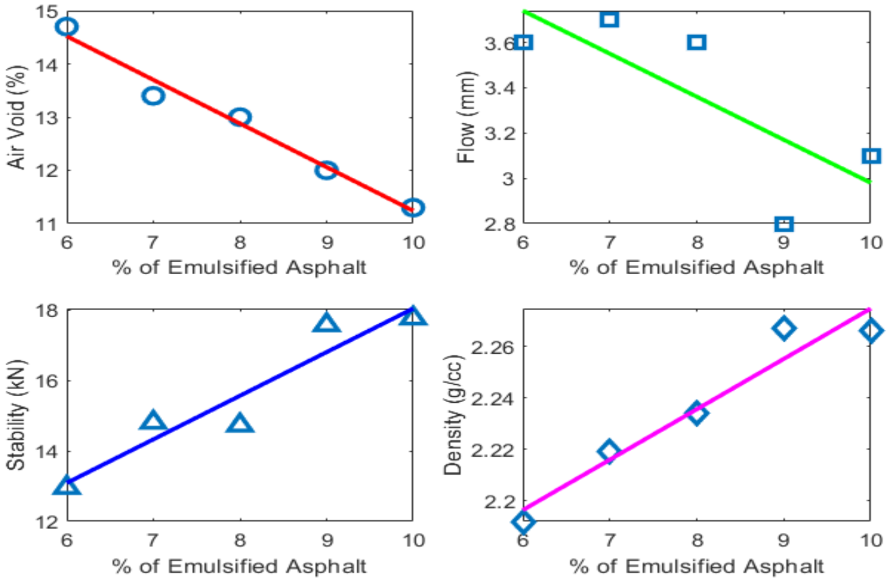

Figure 8: Mix performance at 0% rock filler and 3% cement

3.6 Effect of Fillers on Identical Parameters

Percentage of void in the mix decreased for all combinations as the percentage of cement and bitumen in the mix increased, as shown at Figure 9. The stability of compacted mix increased as percentage of the cement increased but decreased for zero percent cement. The flow rate of compacted mix has variable trend increasing and decreasing characteristics for different proportion of cement. The density of mix of compacted mix increased as percentage of the cement increased.

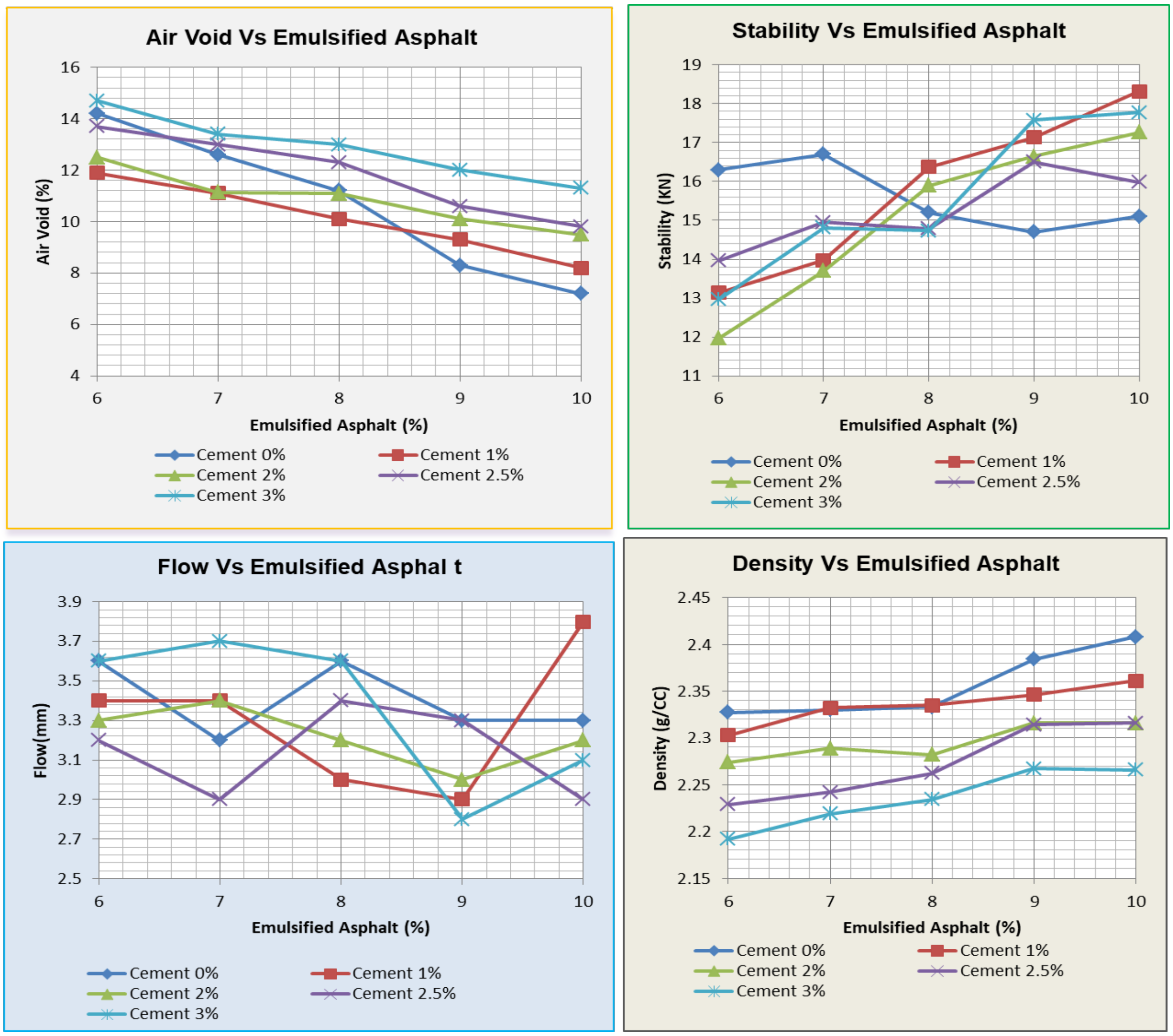

Figure 9: Effect of cement content on mixture properties

3.7 Parameter Properties at the Optimum Emulsified Bitumen Content

The relation between the approximate optimum emulsified bitumen content determined based on the percentage of emulsion content at maximum stability and density of total mix and, the emulsified bitumen content at estimated (median of designed air void of the mixture. Accordingly, the parameter properties for various combinations were estimated at optimum emulsified bitumen content as illustrated in Table 4. This is used to estimate the property of each mix for the designated mixtures combinations.

Table 4: Parameters properties at estimated optimum emulsified bitumen

Id	OEBC (%)	Air Void (%)	Stability (KN)	Flow (mm)	Density (g/cm^3)	Rock Filler and Cement (%)	Emulsified bitumen (%)
1	8.97	8.97	14.57	3.30	2.370	3 & 0	6, 7, 8, 9, 10
2	9.33	7.40	17.00	2.80	2.348	2 & 1	6, 7, 8, 9,10
3	9.53	7.30	16.50	3.10	2.330	1 & 2	6, 7, 8, 9, 10
4	9.00	7.40	16.40	3.40	2.323	0.5 & 2.5	6, 7, 8, 9, 10
5	9.30	7.00	17.58	2.53	2.670	0 & 3	6, 7, 8, 9, 10

As in most studies on cold mix asphalts, the ranges for minimal Marshall stability and Marshall flow values are 3.3 KN to 5.3 KN and 2 mm to 4.5 mm, respectively (Ethiopian Roads Authority, 2016). The requirements are met by the air void content, Marshall stability, Marshall flow value, and density of the mix that are obtained by adjusting the amount of cement and rock filler with the estimated optimum bitumen content, as shown in Table 4.

4. CONCLUSIONS AND RECOMMENDATIONS

Emulsified cold mix asphalt provides a number of benefits that make it a promising alternative to hot mixed asphalt, including reduction in heating energy and emissions, as well as longer working time for transportation, and placement of the mixture. However, the challenges faced in the mix design procedure to control the volumetric and performance limit the widespread use of emulsified cold mix asphalt. The experimental results stated in this research have concentrated on developing a better understanding of the role of Ordinary Portland Cement and Rock Filler in improving the mechanical properties of emulsified asphalt mixtures. The laboratory results of the tests support the mixture properties improved as shown earlier research findings on increasing the stability, density, flow resistance and decreasing air void by adding Ordinary Portland Cement and rock filler.

The findings suggested that the most optimal outcomes were achieved when employing a combination of 2% rock filler and 1% cement filler. Preferably used for mix design demonstration at the field. Large scale advanced performance testing and field trials studies should be carried out for better understanding on the performance of emulsified cold mixes asphalt for low volume road construction for different traffic, climatic and terrain circumstances.

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