Laboratory Evaluation of Cold Mix Asphalt Mixtures for Low Volume Roads

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Abstract: **An efficiently designed highway pays a pivotal role in boosting the economy of developing country like Pakistan. Roads in Pakistan are almost designed as flexible pavement using Hot Mix Asphalt (HMA) mixtures. Besides its prompt adaptability, it encompasses some serious drawbacks as well such as; higher temperature requirements for sufficiently reducing the viscosity of mix for its ease in mixing, handling and compaction which contributes fuel requirements almost 15% of total cost of the project. Additionally, it consumes more natural resources, its non-feasibility in colder region, more transportation charges due to central plant recycling, deficient allowance for recycling and above all it imparts adversely to the environment due to the effect of the greenhouse gases. Cold Mix asphalt (CMA) on the contrary is mixed at the ambient temperature and hence fuel cost is optimized almost to nil, it saves natural resources requirements like aggregates, bitumen by using higher rates of recycling, it facilitates construction in any weather, overall it becomes more cost-efficient and above all it is environmentally friendly. This research aims to use CMA mixture to be utilized for low volume roads, rural roads, in remote areas and for reinstatement works where HMA mixtures will be uneconomical and will rise the risk of environmental pollution. Marshall mix design method is utilized in which mechanical and the volumetric properties of both the HMA and CMA mixtures are investigated and compared, these include; Marshall stability, unit weight and flow value, VMA, VFA and VTM. The results of this research suggest that CMA mixtures were sufficiently rich in the both mechanical and volumetric properties equivalent to 50 to 60% to HMA mixtures and hence these can be utilized for reinstatement works, low volume traffic roads and remote rural roads.**

Keywords: **HMA Mixture, CMA Mixture, Marshall Stability, Marshall Volumetric Properties.**

1. INTRODUCTION:

Hot mix asphalt (HMA) mixtures play a versatile role in the construction of road pavements. Almost all the roads in Pakistan are designed using HMA mixtures. This versatility is attained due to the visco-elastic nature of bitumen which fits it use for all the climatic conditions and copes high vehicular traffic loads through its elastic nature. Besides its versatility, HMA mixtures swift adoptability is due to the early developed superior strengths and prompt availability for traffic opening. However, HMA requires higher temperatures for the production due to the fact that bitumen in its raw state is highly viscous and in order to make its operations of mixing, handling and compaction easier the viscosity of the bitumen is supposed to be sufficiently reduced before use (i.e. pre-heating aggregates and bitumen at the temperature of 175 to 190^0 C and 120 to 125^0 C respectively and then are mixed at 154 to 160^0 C) which demands approximately 15% of the total project cost. Also, HMA mixtures requires central plant for the production i.e. transportation charges and hauling distances further accumulate in the cost, HMA effects adversely to the environment and pollutes the neighboring vicinities, allowance of recycling rate in HMA mixtures is very less practically up to 20% and its production becomes quite difficult in the colder regions.

On the contrary, Cold Mix Asphalt (CMA) technology utilizes other innovative techniques to reduce the viscosity of bitumen binder these include; cut-back asphalt, foaming of bitumen and emulsification of bitumen or bitumen emulsion. This research uses bitumen emulsification technique to reduce the viscosity of bitumen. In this technique 60% bitumen is mixed with 37 to 38% water and 1-2% emulsified agent for producing the homogenous mixture of oil (bitumen) and water. As no heat is involved in CMA process i.e. fuel consumption cost is optimized almost to nil and also due to mixing at the ambient temperature it is green asphalt i.e. environmentally friendly. CMA mixtures are economical, produced and applied at site i.e. transportation and hauling charges are also optimized, recycling rate are higher and due to the ambient temperature mixing CMA mixtures facilitate construction in any weather condition.

Bitumen emulsion is an innovative technique which efficiently reduce or eliminate the use of heat for reducing the viscosity of bitumen by the addition of 37-38% water and for producing the uniform mixture 1-2% emulsifier is mixed with bitumen and water. When two immiscible liquids are mixed together, after the passage of sometime these get separated into two layers due to two reasons i.e. one is the densities difference & action of gravity and the second is the due to the coalescence of bitumen globules. When an emulsifier is mixed exerts the charges on the bitumen globule and hence due to the like charge bitumen globules repel each other and avoid coalescence and further emulsifiers are composed of long hydrocarbon chain which consists of two portions one is hydrophobic (oil loving) and the other side is hydrophilic (water loving) portion and accordingly these ends get attracted to the bitumen and water respectively and therefore the separation of layers is prevented and hence, a homogenous mixture is formed.

Presently CMA mixtures are only being utilized for the small repair & reinstatement works, surfacing dressing and treatments in Pakistan. If these failures of roads were treated by the HMA mixtures it would have accumulated high cost. However, the use of CMA mixtures for such works is very cost-effective, speedy and it is produced and applied at the site without the need of production plants as in case of HMA mixtures.

1.1 LOW VOLUME TRAFFIC ROADS:

For defining the low volume roads, the criteria vary in the different parts of the world. According to the AASHTO guidelines for geometric design of low volume roads, 2nd edition 2019, “A low volume road is functionally classified as minor or local collector road which servers average daily traffic volume of less than 2,000 vehicles per day.” In Pakistan during 2017, the total length of roads has increased to 264,401 thousand km which include both high and low type roads. From the given figure of 264,401 high type roads are about 187,807 km and low types roads are about 75,549 km.

The percentage of low volume type roads is about 28.57% of total roads in Pakistan. However, the same design criteria of high-volume roads are being applied for the construction and design of low volume roads and due to the high prices of the binder like bitumen (which are derived as the byproduct of petroleum) are being used for the design of the low volume traffic roads which contribute about 80 to 85% of the total project cost. If instead of conventional bitumen, a binder like bitumen emulsion is used that will ultimately reduce the cost of the project as the bitumen emulsion consists of only 60% of the bitumen and further the per kg cost of bitumen emulsion is about half the per kg cost of conventional bitumen. Therefore, the utilization of CMA mixture will ultimately decrease the cost of the project and it is environmentally friendly.

1.2 RURAL ROADS:

Pakistan needs to develop the strong rural road network which will boost the economy growth, enhance the agricultural development and generate the employment opportunities in the rural areas. The utilization of HMA mixtures for rural road development is not efficient as HMA mixtures are costly due to the high bitumen rates, environmentally hazardous and require the central production plants.

The use of CMA mixtures in the rural roads’ development will efficiently reduce the cost of the projects, it will facilitate the construction even for the small budgets roads, it will allow the construction in the rainy season without needing the plant, CMA mixtures will be produced and mixed at the site and allowing the construction in hilly areas as well and due to the production at the site the risk of long hauling distances i.e. setting of bitumen before reaching at site is reduced as in case of HMA mixtures further the transportation charges are minimized to nil.

II. LITERATURE REVIEW:

A research study was conducted to evaluate and advance the cold emulsion mixtures properties, repeated load axil creep, indirect tensile stiffness modulus (ITSM) and fatigue were under consideration. After the evaluation, a 2000 MPa ITSM was targeted for the comparison with HMA mixtures. It was concluded that even when CMA mixtures were designed efficiently and cured properly, exhibited almost similar stiffness as HMA mixtures. Also, with the addition of 1-2% Portland cement, strength, ITSM and creep resistance were improved. However, HMA yet dominant in the fatigue resistance performance. (I.N.A Thanaya Beng, 2009.)

In this research study, the suitability of reclaimed asphalt concrete as a cold mix surfacing material for low volume roads was carried out. The study objective was to ensure the suitability of mixture of reclaimed asphalt pavement, cationic bitumen and virgin bitumen for low volume roads. Same gradation of aggregates and reclaimed asphalt concrete was carried out to achieve the gradation curve within the failure envelope and quantity of bitumen emulsion was determined using the aggregate gradation and modified Marshall mix design procedure was adopted to evaluate the strength of mixture.

A targeted stability of 3336 N for medium traffic roads (Asphalt Institute Design Manual Series, 1994) was fixed. From the tests results, 6900 N stability was achieved at the 5.2% optimum emulsion content which gives the performance justification of cold mix asphalt. Further, it was concluded that these cold mixes are sufficient to be utilized for medium and low traffic roads, cost-efficient and environmentally friendly. (Chrispus Sifuma Ndinyo, Zachary Abiero Gariy, Stephen M. Mulei, 2013.)

In this research study, emulsion cold mix asphalt was used in the UK and after the design of cold mix asphalt mixture, the laboratory experience and the field observations were presented. CMA mixture which was used on the strategic highway trunk road A90 site trial in 2008 which played a traffic volume of 10 million equivalent standards (80KN) axle load saved 43 tons of CO_2 emission which is still performing well.

Simulation of in-situ curing was carried out in the laboratory and the indirect tensile stiffness modulus was achieved in 6 months at 10 ^{0}C of 5 GPa. Bitumen binder recovered from the site core was comparable to the HMA mixtures and wheel tracking of site cores exhibited excellent resistance to the deformation. It was concluded that the CMA mixtures performed satisfactory results and these mixtures can be used for the design of low to medium volume roads. (Dennis Day, Ian Michael Lancaster, Dougie McKay, 2019.)

In this research study, production and durability of cold mix asphalt was investigated. Bitumen emulsion was mixed with the aggregates as the binder and heavily trafficked roads as base course were designed using cold mix asphalt two years ago. The strength of the cold mix asphalt is dependent on the breaking rate of bitumen emulsion, an attempt was made to predict the breaking rate of the bitumen emulsion and it was found that the breaking rate of bitumen emulsion had strong relationship with aggregate surface area and mineral type. Further, the durability of cold mix asphalt was assured which was constructed 15 years ago.

Cold mix asphalt was found durable in spite of the high air void content which results in the aging and cracking but the road surfaces were in good condition and only few cracks were observed in after 15 years paving. The recovered binder from cores showed high penetration and softening points. As cold mix asphalt is environmentally friendly due to low emission of toxic gases and its high durability makes these mixes very promising for the future use even for the high trafficked roads alike hot mix asphalt mixtures. (Roger Lundberg, Torbjörn Jacobson, Per Redelius, Jenny-Ann Östlund, 2016.)

In this research study, cold bituminous emulsion mixtures were designed for the low volume roads and the study was carried out in Czech Republic, as there was the lack of unified mix design criteria for cold bituminous asphalt mixture so, the study focused on the development of mix design procedure for cold bituminous emulsion mixtures and further, a trail road section was analyzed. A low volume traffic road was selected for trial section to analyze the effects of traffic volumes and weather conditions.

Total six subsections were constructed with in the trial mix, this paper presents 1st subsection containing 30 % RAP. It was concluded that the project was successfully finished. The cold bituminous mixtures performed satisfactory and further these mixtures were recommended to the contractor for the use. (Rajan Choudhry, Abhijit Mondal and Harshad S. Kaulgud, 2012)

III. MATERIALS EVALUATION:

3.1 Aggregates:

Aggregates used were crushed limestone which were collected from Noori-Abad quarry. Samples of aggregate were chosen from four different sized stockpiles namely; 25mm, 20mm, 12mm and 5mm. Subsequently, different physical properties of aggregates were evaluated by conducting various tests for ensuring the suitability and then the gradation of aggregates was designed for the HMA mixtures (and the same was used for CMA mixtures) using ASTM C 117, 136. Table 1. and table 2. given below, show the designed gradation and physical properties of aggregates respectively. Further in figure 1. achieved gradation curve is provided.

Table 1. (Gradation of All the mixtures)

SIEVE SIZE		Passing Percentage %				
Inch	**mm**	**Control HMA Mix**	**RAP Extracted Aggregate**	**Control CRM**	**Midpoint specification**	**Specification limit**
1 ½ “	38.1	100	100	100	100	100
1”	25.4	100	100	100	100	100
3/4”	19.1	96	84.8	91	95	90- 100
1/2”	12.7	79.3	45.5	67	---	---
3/8”	9.52	63.9	28.6	57	63	56-70
#4	4.76	41.8	7	41.5	42.5	35-50
#8	2.40	30.2	1.9	30.5	29	23-35
#50	0.30	7.9	0.6	8	8.5	5-12
#200	0.075	2.8	0.3	3	5	2-8

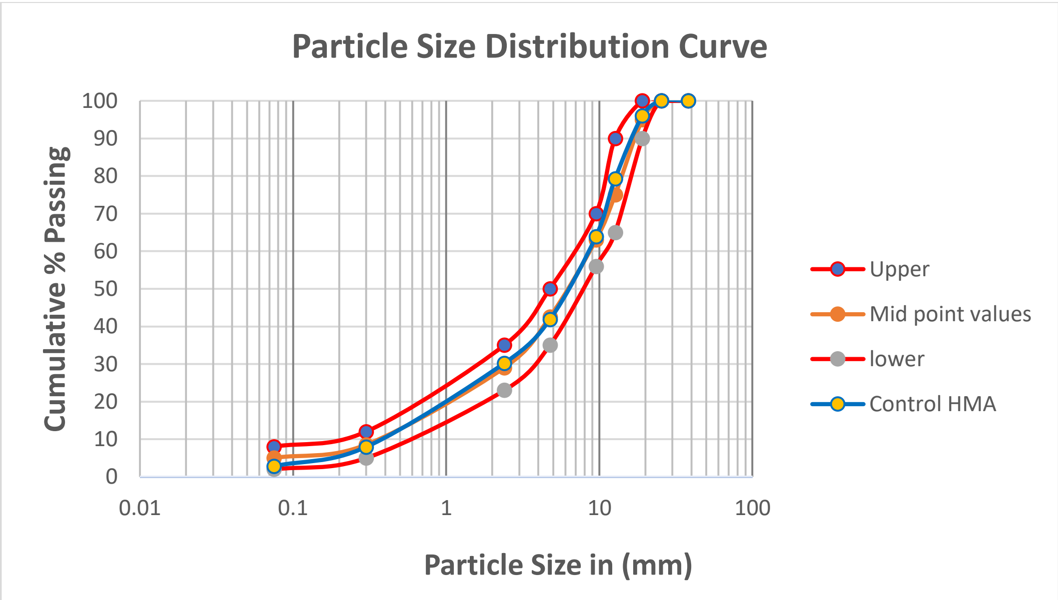

Figure 1. (Particle Size Distribution of HMA mixtures)

Table 2. (Outcomes of Various tests of Aggregates)

Test Particulars	Results obtained from tests
L.A Abrasion Value %	21
Impact value of aggregate %	21.3
Water Absorption %	1.17%
Specific gravity of Coarse Aggregate	2.613
Specific gravity of fine Aggregate	2.615
Specific gravity of RAP Aggregate	2.498

3.2 Bitumen: Control HMA mixture was designed using bitumen of 60/70 penetration grade, obtained from a Karachi refinery. Further, following physical tests (given in table 3.) were conducted for evaluating the suitability of binder.

Table 3. (Properties of Bitumen used in HMA)

Properties	Results
Penetration (0.1 mm) at 25 ^{0}C	66
Ductility in (cm) at 25 ^{0}C	130+
Softening point, ^{0}C	46
Fire point, ^{0}C	363^0
Flash point, ^{0}C	319^0
Specific gravity (at 25 ^{0}C)	1.006

3.3 Bitumen Emulsion: Selection of bitumen emulsion is slightly complex process because it requires a specific knowledge regarding the characteristics of aggregates. Every aggregate has a definite dispersing charge and based on that charge its reactivity is decided. For example, acidic aggregate contains high silicon (SiO_2) and disperse negative charge and therefore it will exhibit good reactivity with the bitumen emulsion dispersing positive charge as in case of Cationic emulsion. And when basic aggregates are used, they disperse positive charges and therefore anionic type of emulsion is to be used which disperse negative charge. In this research study, Cationic Slow Set (CSS-1h) bitumen emulsion is used. Slow set emulsion helps coating high surface area aggregates like fillers. Results of physical tests on bitumen emulsion are presented below in table 4.

Table 4. (Properties of Cationic Slow Set Emulsion)

Tests on bitumen emulsion	Results
Particle Charge test	Positive
Saybolt-Furol, Viscosity, 25 ^{0}C SFS	24
Residue by Distillation, %	60
Specific gravity	1.0185
Ductility, 25 ^{0}C, 5cm/min, cm	100
Penetration, 25 ^{0}C, 100gm, 5s mm	62
Solubility in trichloroethylene %	98.5

IV. RESEARCH METHODOLOGY

Control HMA mixture is designed by Marshall mixture design procedure. The design phase involves the proportioning of aggregates from four different aggregate sizes and the percentage of bitumen binder required to give sufficient coating for generating stiff mixture. five different bitumen contents i.e. (3, 3.5, 4.0, 4.5 and 5) % three replicating each content i.e. 15 samples are prepared for Control HMA mixture. Selected proportioning of aggregates has already been mentioned above. In order to determine percentage of binder, a 1200 gm Marshall specimen (containing aggregates, filler and bitumen) is prepared by heating aggregates and bitumen at 175 to 190^0 C and 120 to 125^0 C respectively and then are mixed at the temperature of 154 to 160^0 C in a preheated Marshall mold (10 cm in diameter and 7.5 cm in height) having temperature 138 to 149^0 C and the compaction is carried out with 75 blows of Marshall hammer on each face of the specimen. Later on specimen is left for one hour in the mold and then for 24 hours at the room temperature.

After that specimen volumetric properties are evaluated and for the determination of specimen mechanical properties (flow value & stability) it is immersed in a water bath for 1 hour at 60^0 C and then is tested using Marshall mix design apparatus. Then optimum bitumen content is determined by taking the average of three bitumen contents at (higher stability, higher density and 4% air voids).

CMA mixture was also designed using Marshall mixture design procedure mentioned before i.e. Similar aggregate blend, determination of mixture mechanical and volumetric properties and evaluation of optimum content of emulsion.
However, design procedure was slightly modified than HMA mixtures. these are given below:
(a) Initial residual asphalt content (IRAC) was determined which gives the initial quantity of bitumen emulsion.
(b) In order to achieve uniform coating, the evaluation of Optimum total liquid content (OTLC) was carried out.
(c) Unlike HMA, CMA mixture was cold mixed at the room temperature.
(d) After the compaction, curing process for CMA mixture was slightly modified from HMA mixture.

Determination of IRAC and OTLC is carried out by utilizing the Manual Series MS-(14) of Asphalt Institute, 1989 details are shown below.

Step 1: Aggregates gradation based on guidelines of manual series 14 of Asphalt Institute 1989, for the dense graded mixtures.
Step 2: Evaluation of IRAC & initial emulsion content (IEC).

P is used to designate the IRAC the percentage of IRAC which is calculated using the following formula.

$$P = (0.05\,A + 0.1\,B + 0.5\,C) \times (0.7) \quad (1)$$

Where A = shows the percentage of aggregate which retains on 2.36 mm sieve (no. 8 sieve)

B = percentage of aggregate passing 2.36 mm sieve & retains on 0.075 mm sieve &

C = show the percentage of aggregate passing 0.075 mm sieve.

IEC is evaluated using the following.

$$IEC = (P/X)\ [\%] \quad (2)$$

Where X represents bitumen content which is 60 % in this case.

Step 3: Aggregate coating test

For the determination of percentage coating based upon visual observation, specimen of 1200 gm weight at IEC was mixed dry with (the aggregates, mineral filler and varying amount of pre-wetted water) at the room temperature and later, bitumen emulsion is mixed for 2 to 3 minutes for even coating. Based on IRAC different pre-wetted water contents staring from (3, 3.5, 4, 4.5 & 5) % were selected by the weight of total mixtures and varied by 0.5 %. Water content, where the best aggregate coating with emulsion was observed with the less water content was considered as Optimum pre-wetted water content (OPW_{WC}) which is 4.5% in this case.

Step 4: Evaluation of OTLC at compaction level.

Keeping the IEC and OPW_{WC} constant the compaction of specimen was carried out by applying 75 blows of Marshall hammer. Keeping OPW_{WC} constant specimens were varied at 1% air drying and compacted i.e. (10%, 9%, 8% & 7%) and these were tested for dry density. The specimen which gave the maximum dry density the OTLC was selected of that specimen content. In this case, it was found at 9%.

Step 5: Evaluation of Residual Asphalt Content (RAC)

RAC was determined by varying the IRAC two points above and below by 0.5% step. keeping the OTLC constant i.e. (5.5%, 6%, 6.5%, 7% and 7.5%). Total 15 samples were compacted i.e. three replicates of each % by applying 75 blows of Marshall hammer on each specimen side and later, specimen was kept in mold for 24 hours and then extruded and placed at 40ºC for 72 hours in the oven. because strength development is based on emulsion braking i.e. water evaporation and later, maintained again for 24 hours at the room temperature and finally specimen volumetric & mechanical properties were evaluated. Then, ORAC was determined similarly as optimum bitumen content for HMA mixtures.

Table 5: Evaluated CMA mixtures design parameters

Initial residual asphalt content (P) %	Initial emulsion content (IEC) %	Optimum pre-wetted water (OPWwc) %	Optimum total liquid content (OTLC) %
6.5	11	4.5	9

V. RESULTS

Table 6: Results of Control HMA Mixtures

Properties	Bitumen Content %				
	3.0	3.5	4.0	4.5	5.0
Stability in (Kgs)	1240	1365	1605	1440	1380
Plastic flow in 0.01”	7.8	8.5	10.2	11.6	12.4
Unit weight of mix (g/cm^2)	2.23	2.27	2.39	2.36	2.33
V.M.A (%)	16.2	15.4	15.7	16.1	16.4
V.T.M (%)	7.3	6.1	5.2	4.9	3.9
V.F.A (%)	54.9	60.4	66.8	69.6	76.2

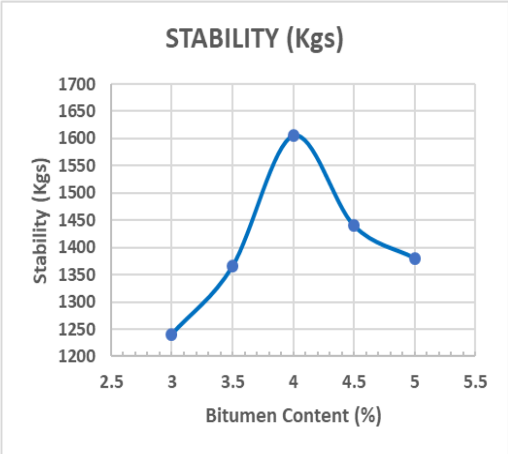

Fig 2. Marshall stability vs Bitumen content

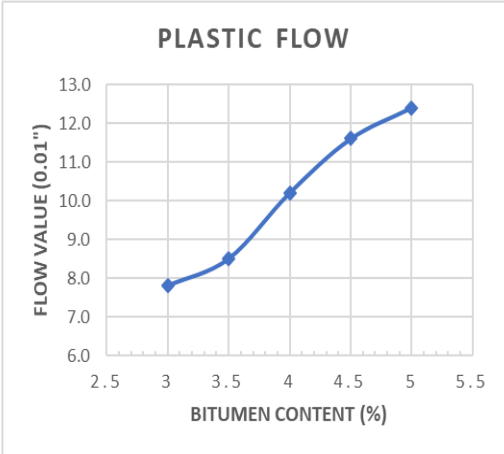

Fig 3. Plastic flow vs Bitumen content

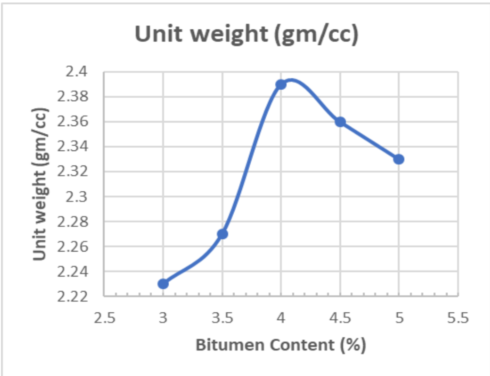

Fig 4. Unit weight vs Bitumen content

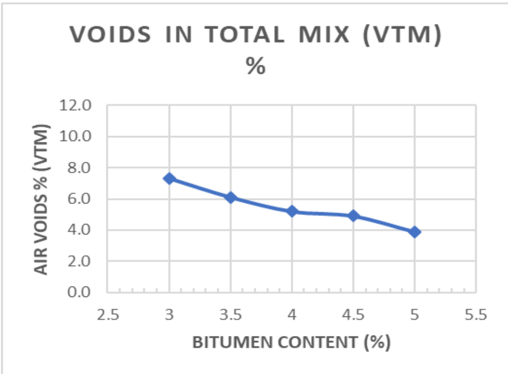

Fig 5. VTM vs Bitumen content

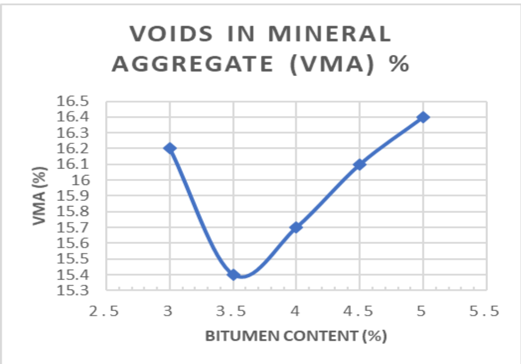

Fig 6. VMA vs Bitumen content

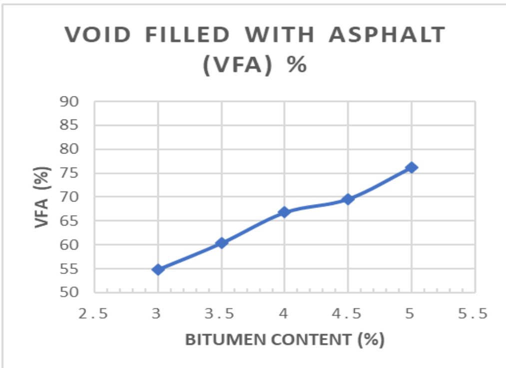

Fig 7. VFA vs Bitumen content

In fig 2. the variation of Marshall stability of HMA mixture with bitumen content ranging from 3% to 5% is shown. It can be seen that stability shows the linear regression with increasing bitumen content up to 4% where the maximum stability of 1605 kgs is achieved and after that the stability decreases with further increase in the bitumen content. The earlier rise of stability up to 4% bitumen content is exhibited due to the increase in the coating ability due to the sufficient bitumen and therefore more compacted and strengthen mixture is formed. Later beyond 4% bitumen content which is more than the optimum content and therefore this extra bitumen causes the sliding of aggregates and filler materials and ultimately it reduces the strength of mixture.

Fig 3. Shows the variation of plastic flow value with bitumen content ranging from 3% to 5% and it can be seen that plastic flow value starts from 7.8 (3% B.C) to 12.4 (5% B.C) which shows the linear regression or continuous increase of plastic flow value with the increase in the bitumen content. Flow value gives the plastic deformation value at the failure point and the linear increase is due to the segregation of aggregates and filler with bitumen content which increases with increase content.

Fig 4. Shows the variation of unit weight of HMA mixture with bitumen content ranging from 3% to 5%. Initially, unit weight of mixture increases linearly with increased bitumen content up to the 4% content where it is found to be 2.39 and afterwards with the further increase of bitumen content the unit weight of mixture decreases. Initial increment in the unit weight after the edition of bitumen content is due to the reduction of air voids in the mixtures and ultimately the reduction in the volume of mix and hence the unit weight increases. Beyond 4% bitumen content further increase in the bitumen content fills the voids of aggregates in the mixture and causes the bleeding of mixture which slides the filler aggregates and ultimately reduces the unit weight of mixture.

Fig 5. Shows the relationship of air void content with the bitumen content and it can be clearly seen that the air void content linearly decreases with increased bitumen content starting from 7.3 to 3.9. The continuous decrement in the void content of the mixture is due to the addition of bitumen content which fills the bitumen in the voids of aggregates and eliminate the air content and therefore the air void reduces continuously with bitumen addition.

Fig 6. Shows the plot of voids in mineral aggregates (VMA) against the bitumen content. As it is clear from the figure that at 3.5% bitumen content VMA decreases from 16.2 % to 15.2% and with the further increase in the bitumen content VMA linearly increases with the bitumen content and at 5% content the maximum value of VMA achieved is 16.4%.

Fig 7. displays the plot of voids filled with asphalt (VFA) against the bitumen content. It is clearly seen that from the 3% to 5% bitumen content increment, the VFA continuously increases because of the expulsion of air from the voids and these voids get filled with the bitumen content so its percentage increases linearly.

Table 7. Shows the revised Marshall properties with OBC

Properties of HMA mixtures	OBC = 4.26 %
Stability in (Kgs)	1540
Flow value (0.01")	11
Unit weight (gm/cm^3)	2.39
VTM (%)	5
VFA (%)	68
VMA (%)	15.9

Table 8. Shows the results of CMA mixtures

Properties	Emulsion Content %				
	5.5	6.0	6.5	7.0	7.5
Stability in (Kgs)	512	645	724	792	703
Flow in 0.01"	2.6	3.4	4.2	4.8	5.3
Unit weight of mix (g/cm^2)	2.05	2.13	2.22	2.17	2.10
V.T.M (%)	15.1	11.9	11.2	9.5	7.3
V.M.A (%)	22.4	18.3	18.6	20.7	22.8
V.F.A (%)	32.6	34.9	40	54	67.9

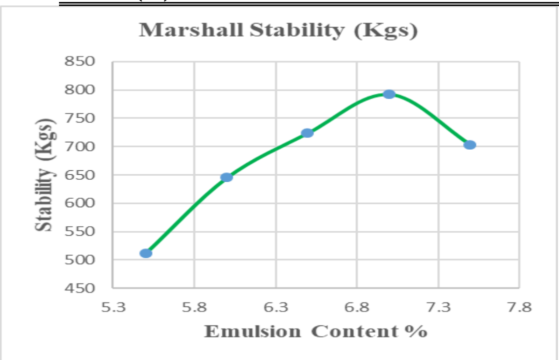

Fig 8. Shows Stability vs Emulsion content

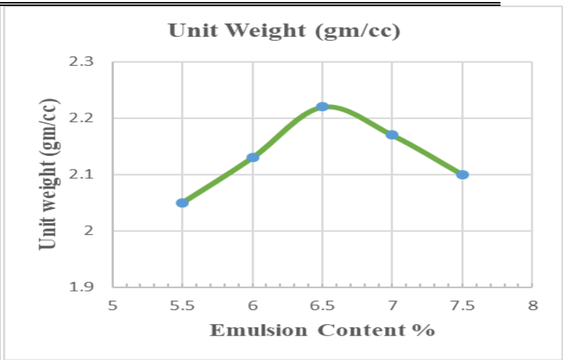

Fig 9. Shows unit weight vs Emulsion content

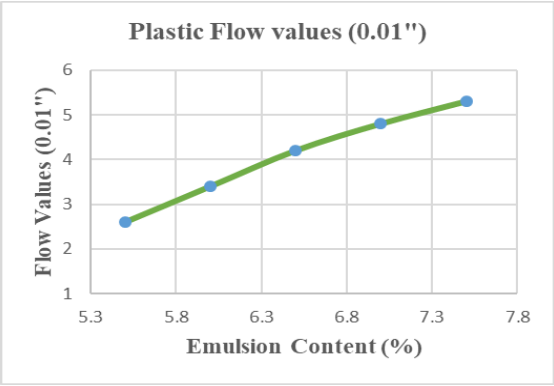

Fig 10. Plastic flow vs Emulsion content

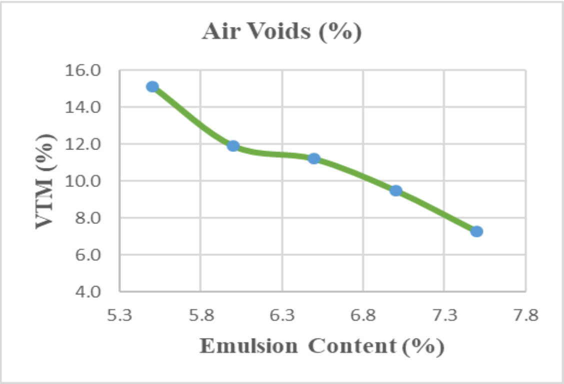

Fig 11. Air voids vs Emulsion content

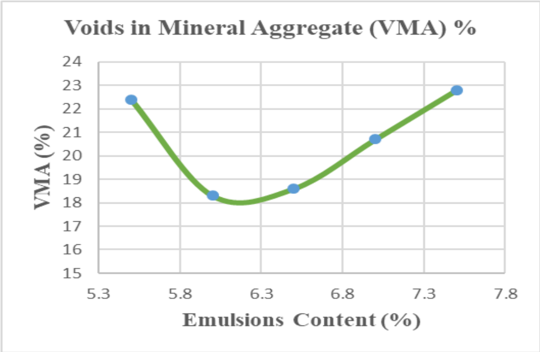

Fig 12. VMA vs Emulsion content

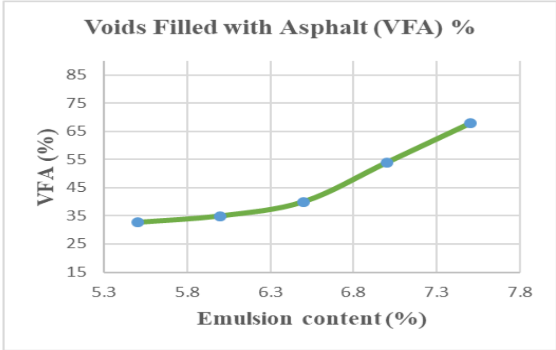

Fig 13. VFA vs Emulsion content

Fig 8. Shows the graph of Marshall stability of CMA mixture against the varying emulsion content i.e. from 5.5 % to 7.5%. It is clear from the figure that the stability of CMA mixture increases linearly with the increased emulsion content up to 7% where its maximum value found is 792 kgs. Further beyond this point the increase in the emulsion content reduces the stability this is due to fact that up to 7% increasing emulsion content improves the coating ability resulting a stiff mixture and beyond that emulsion content the excess emulsion content slides the filler aggregates and reduces the stiffness of mixture.

Fig 9. Shows the plot of unit weight of the CMA mixture against the increasing emulsion content and it is observed that initially the unit weight of the mixture increases with the increased emulsion content up to 6.5% and the maximum unit weight observed at that 2.22 gm/cc and beyond this content the unit weight decreases. This first rise in the curve is due to the reduction in the air voids and volume of the mixture and ultimately it reduces the unit weight and beyond this point increased emulsion content causes the bleeding and reduces the unit weight of the mixture.

Fig 10. is the plot between the plastic flow value and emulsion content and it is observed from the figure that plastic flow is the deformation of the CMA mixture at the failure point and it linearly increases with the increasing emulsion content.

Fig 11. Shows the plot of air voids against the bitumen emulsion content and it is clear from the figure that air voids of the mixtures are continuously reducing due to bitumen emulsion which fills the void spaces of the mixtures and therefore reduce the air content of the mixture.

Fig 12. Shows the plot of voids of mineral aggregate (VMA) vs the emulsion content and the VMA is the property of the aggregates and it first decreases due to the reduction of air voids and further it increases due to the voids filled by the addition of emulsion content.

Fig 13. Shows the plot of voids filled with asphalt (VFA) vs emulsion content and it is observed that the VFA linearly increases with the increased emulsion content because the all voids of aggregates get filled with the bitumen emulsion content.

Table 9. Optimum Emulsion Content (OEC) for CMA mixtures

Properties	**OC = 6.75 %**
Stability in (Kgs)	760
Flow (0.01")	4.5
Unit weight (gm/cm^3)	2.2
VFA (%)	47
VTM (%)	10.5
VMA (%)	19.5

IV. COMPARISON B/W RESULTS OF HMA AND CMA:

After the cost comparison of the two mixtures and the environmental impact the have on the atmosphere, the basic properties and performance criteria is discussed here. The criteria of the Marshall mix design procedure for the low volume roads is;

- ✓ Minimum Stability is 226.7 kgs and for medium roads it is 340 kgs.
- ✓ Flow value from 8 to 20.
- ✓ Air voids should range between 3 to 5%

It can be observed from the table 9. that the stability achieved is 760 kgs which even exceeds the minimum stability criteria for medium volume roads and further the flow value is less than 8 which gives indicate that the plastic deformation is less and only the problem which these mixture is these contain high air voids, however these mixtures are only designed for the low volume roads so, the effect of high air voids content will not cause a serious problem and further with the addition of other filler and Cementitious materials these CMA mixtures can be produced with the less air voids and more stability and even these CMA mixtures can be adopted for the high duty pavements as well.

V. CONCLUSION

After the evaluation of mechanical and volumetric properties of both the HMA and CMA control mix, the following conclusion can be drawn.

- Although, HMA mixtures are adopted universally for the design of flexible pavements due to the early developed superior strengths and rapid traffic opening availability but the fuel requirements of such mixtures is 15% of total project cost and environmental is adversely effect due to the release of toxic gases and further due to the central production plants, hauling and transportation charges make it uneconomical.
- CMA mixtures use no heat for the production or mixing i.e. fuel requirements are nil, it is economical, environmentally friendly, facilitates the construction in any weather condition, it allows higher recycling rates and it is produced and applied at site.
- Though, presently in Pakistan CMA mixtures are only utilized for the repair and reinstatement works and for surfacing dressing etc. which does save energy and cost in comparison to HMA mixtures. But these mixtures can also be utilized for the low volume traffic and rural roads which comprises 28.6% total roads of Pakistan. If these roads are constructed with HMA mixtures will be uneconomical and it will pollute the environment.
- After the evaluation of mechanical and volumetric properties it is evident that CMA mixtures obey all the ranges of Marshall mix design criteria and have strengths approximately 50 to 60% of HMA mixtures. Also CMA mixtures fulfill the minimum stability requirements (i.e. 226.7 kgs) of the low volume road and even these mixtures are very stiffed to be utilized for the high duty pavements.
- However, CMA mixtures are poor in term of early development of strengths and air voids are more than the required limits. However as for as the scope of this study is concern, these CMA mixtures are sufficient to perform the duties for which these are designed. Further, if it is intended to use these mixtures in the high duty pavements then partial replacement of aggregate mineral filler can be carried out by cementitious filler to help in developing early strengths and reduce the air content of the mixtures.

VI. RECOMMENDATION

1. Marshall mix design procedure was used for the evaluation of the properties of both the mixtures i.e. HMA and CMA. Further other design methods which are performance or model study based should be used for simulating the real field scenario.
2. volumetric and mechanical properties of both HMA and CMA mixture were evaluated and further studies must be carried out to evaluate the other properties of the mixtures like, moisture susceptibility, durability potential and rutting & fatigue cracking tests.
3. Aggregates were crashed limestone obtained from the quarry of Noori-Abad and further investigation on materials different regions should be carried out.
4. Cationic slow set bitumen emulsion with low viscosity and hard penetration (CSS-1h) was used in the research due to the compatibility with crushed limestone aggregates but as different quarries of aggregates are suggested so, the other bitumen emulsion types like (CMS), (CRS), (ASS), (AMS) and (ARS) should be tried.

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