WARM MIX ASPHALT INVESTIGATION ON PUBLIC ROADS-A REVIEW

Rajiv Kumar and Satish Chandra

Department of Civil Engineering, Indian Institute of Technology- Roorkee, Roorkee, India

ABSTRACT

Warm mix asphalt has been introduced in Europe in 1997 and in the United State 2002. The first trail of warm mix asphalt has done publically in Europe in 1999, in U.S.A 2004 and in India 2009. Most of countries like Germany, Norway, France, U.S.A, Canada, China, Korea, South Africa, India and Brazil have successfully used the WMA construction on public roads after successful laboratory test. The WMA is more success in U.S.A compare to European countries (EAPA, 2014). The main goal of WMA is to produce the bituminous mixtures with similar strength, durability and performance characteristics as HMA substantially reduced the mixing and compaction temperature.

This study focus on history and development of warm mix asphalt in different countries including advantage and disadvantage of warm mix asphalt. This paper also reviews the warm mix asphalt in India.

KEYWORDS

Warm Mix Asphalt, Hot Mix Asphalt, Emission, Rutting, Moisture Susceptibility, Fatigue, WMT, Temperature.

1. INTRODUCTION

A bituminous mixture is a combination of bituminous materials (asphalt binders), properly graded aggregates and additives. Bituminous mixture has divided in to four categories on the basis of mixing temperature (NCHRP 691), a) cold mix: produced at near ambient temperature. b) Half Warm Mix Asphalt: produced at less than boiling point of water (100°C) but the mix is still heated. c) Warm Mix Asphalt: produce at temperature lower than 20° to 30°C of traditional HMA but still the temperature is more than boiling point of water (100°C). d) Hot Mix Asphalt: produced at temperature 140° to 163°C depending on many factor but mainly on grading of bitumen. The main goal of WMA is reduce the mixing and compaction temperature with similar or better strength, durability and performance characteristics as HMA. [1]

Warm mix technology was introduced in the Europe in late 1990 mainly to reduce the greenhouse gas emissions under Kyoto protocol. Warm mix asphalt has been introduced in Europe in 1997 and in the United State 2002. The first trail of warm mix asphalt has done publically in Europe in 1999, in U.S.A 2004 and in India 2009. Most of countries like Germany, Norway, France, U.S.A, Canada, China, Korea, South Africa, India and Brazil have successfully used the WMA construction on public roads after successful laboratory test and WMA has constructed on public road, the data has given in Table 1.

Table 1 First trial of WMA on public roads

1^{ST} TRIAL(Year)	COUNTRY	LENGTH(Km)	WMA(Additive)
1999	Germany	*	Aspha-min^{R}
1999	Norway	*	*
2000	France	*	*
2004	U.S.A	*	*
2005	Canada	*	*
2007	China	1.00	Evotherm
2008	Korea	0.24	LEADCAP WMA
2008	South Africa	*	WMA-T
2009	India	0.50	Thiopave
2010	Brazil	0.40	Gemul XT14

Note –'*' Information is not available

The WMA is more success in U.S.A compare to European countries (EAPA, 2014). [2] In USA all 50 state has accepted the warm mix technology. WMA can use as a base course, wearing course and maintenance treatment of the pavement. To improve the workability of WMA at low temperature can be done by reducing the viscosity of binder or decrease the frictional resistance between binder and aggregate. On this basis there are three type of warm mix additive (NCHRP-9-47-A, 2014): [3]

A. Organic Warm Mix Additive: the additive which have melting point less than the normal production temperature of HMA that can be added to reduce the viscosity of the asphalt. Example –Sasobit, Asphaltan-B, Licomont BS-100 etc
B. Chemical Warm Mix Additive**:** The additive which reduces the internal friction between binder and aggregate particles during mixing and compaction but doesn't rely on the principles of foaming or viscosity reduction. Example –Evotherm, Rediset, Cecabase etc.
C. Foaming warm mix additive:

   a. Water bearing additive: it contain synthetic zeolites, which are composed of alumina silicates and alkali metals. The synthetic zeolites have crystalline water which release at more than 100°C that create the foam in binder and it increase the volume of binder and reduce the viscosity. Example –Aspha Min, Advera etc.
   b. Water Based Processes: The water-based process utilizes water only to generate bubbles when contacting the hot binder. Example- Double Barrel Green, WAM Foam, green Machine (Gencor), LEA (McConnaughay) etc.

1.1 Germany

In Germany many test sections and commercial applications of WMA were constructed between 1998 and 2001. The first trial of public road was constructed in 1999. The BASt (German Federal Highway Research Institute) has monitored seven test sections. Out of seven section there was six section were SMA and one was a dense-graded mix. Based on laboratory and field performance data in all cases, the test sections of WMA had better or same performance than the

HMA sections. Fischer-Tropsch wax, fatty acid amide and montan wax were used as viscosity changing additives in Germany. Modern foaming technologies were also introduced in Germany at the time of zeolite and Shell Bitumen patented a foaming technology by name of WAM-Foam. Since then, different new foaming principles have been introduced to the market that allows reduction in mixing and compaction temperature even below the vaporisation point of water [4].

1.2 Norway

The first test sections with WAM-Foam in Norway were built in 1999. Also in Norway the overall conclusion is that the WAM-Foam sections appeared to perform similar performance as previous HMA overlays. In 2007, a team of U.S.A. materials experts visited and found that the average reduction in CO-28.5%, CO_2 -31.5%, NO_2-61.5% and Dust-54% in construction of WMA compare with HMA [5].

1.3 France

In 2007, a team of U.S.A. materials experts visited France and they have found that WMA have longer haul distance compare with HMA. The water absorption for the aggregate is maximum 1% where as in U.S.A it is up to 5%. The department of Eure-et-Loir inference also believe that WMA technologies can be used to extend the paving season. The average reduction in CO_2 -23%, SO_2-18%, VOC-19% and NO_2-18% in construction of WMA compare with HMA. In France each contractor is trying to develop its own process. Low Energy Asphalt (LEA) is a warm asphalt production technique developed by Fairco and Appia in France [6].

1.4 Canada

The first WMA trials in Canada were carried out in 2005 in Alberta, Ontario and Quebec. Five different systems were tested in Canada in 2005, Aspha-min® zeolites, Sasobit, Evotherm, WAM (Warm Asphalt Mix) and Colas 3E DB systems. The first Canadian WMA papers were presented at Canadian Technical Asphalt Association (CTAA) in 2006. In 2007, there were several trials were carried out in five provinces using seven different processes [6].

1.5 China

An Evotherm warm mix asphalt test road was paved in 2007 at low a low air temperature in China, which was successfully WMA construction. The AC-13 warm mix asphalt test road was paved successfully in December 2007 in China [7]. The test road was 1 km long, the thickness of AC-13 was 4 cm, and width was 11m. It has started in the morning by firstly manufacturing 500 tons mixture according to DAT process. The test road was paved at an air temperature of 3°C and a wind speed of 20 mph. The field compaction has done with 2 passes with steel wheel roller (1^{st} passes with vibratory mode), 6 passes with pneumatic tire roller and then final 2 passes with the steel wheel roller. The load of steel roller was 16 tons and pneumatic tire roller was 30 tons, the speed of roller was 3-4 meter per minute.

The paving of world's highest highway G219 by WMA, which exist between China's xinjiang province and Tibet at attitude of 3500 meter, at the time of construction the weather temperature, was -2°C to 4° C [8].

1.6 Korea

Korea Institute of Construction Technology (KICT) and Kumho Petrochemical Co. LTD. has jointly invented an innovative WMA LEADCAP (low energy and low carbon-dioxide asphalt pavement) additive. The first trial in Korea of WMA with LEADCAP additive was carried out in 2008 [9].

1.7 South Africa

From the November 2008 to December 2010, rapid progress was made to bring warm mix asphalt into implementation for routine use. Over a period of two years, through a series of national trials, South Africa's WMA knowledge and experience has been increasing exponentially. This knowledge and experience has been sufficient to produce the first iteration of a national WMA specification and a best practice WMA guideline document. WMA South Africa was approved by the eThekwini Municipality for full scale implementation on their road rehabilitation project [10].

1.8 Brazil

The field trial in Campinas city, Sao Paulo state from Brazil, was conducted on Bandeirantes Highway, a three-lane road through a heavily trafficked area which is under private concession since 1998 (Grupo CCR) [11].

The project consisted in overlay the old asphalt pavement with new asphalt (30-mm thickness), in order to improve the pavement surface texture/friction. Paving began in July 2010 and was finished in September 2010. The HMA section was divided in two parts and the WMA section was installed between them. One should mention that both HMA sections are equal (the same materials). The WMA section was 400m length.

1.9 U.S.A

The first trials in U.S.A were carried out in 2004 after seeing the successful implementation of WMA in European countries. Based on the review of literature and survey on web site it is evident that there are approx., thirty warm mix technologies present and out of these 30, two third are Foaming based technology. Reduction of mixing and compaction temperature of WMA is due to use of warm mix additive. WMA technology has been used in all types of asphalt concrete, including stone matrix, dense-graded, porous, and mastic asphalt.

The survey was conducted by NAPA under contract to FHWA and it was found that about 86.7 million tons of WMA used in 2012 which is increased by 26 percent in one year. And it has increased by 416 percent since 2009 which was the first survey conducted. The survey was conducted again in mid-2014; Result from 249 companies with 1281 plants in all 50 sate of United States of America. The techniques used in USA in 2012 are (EAPA, 2014): Plant Foaming 88.1%, Chemical Additive 9.6%, Additive Foaming 2.1% and Organic Additive 0.2% [2].

The survey, conducted by NAPA under contract to FHWA, found that about 86.7 million tons of WMA used in 2012 which is increased by 26 percent in one year.

And it has increased by 416 percent since 2009 which was the first survey conducted as given in Table 5. The following table shows the data of 2009 – 2012. The survey was conducted again in mid-2014; Result from 249 companies with 1281 plants in all 50 sate of United States of America as shown in Table 2.

Table 2 MWA production in U.S.A during 2009-2013

Year	Million tonnes of WMA	Total asphalt production [Million tonnes]	% WMA
2009	15.2	325	5
2010	37.3	326	11
2011	62.3	332	19
2012	77.1	323.5	24
2013	106.4	*	33.3

Note- '*' Information is not available

NCHRP Reports: United States has started working on different parameter of WMA in various projects which is given on Table 3. Some of the project is completed and some of project is in active state are given in Table 3.

NCHRP 9-43: This project has started in 22nd march 2007 and it has completed on 31th January 2011. The total fund for this project was $522,501. Objective of this project was to develop a mix design method for warm mix asphalt (WMA) in the form of a draft AASHTO-recommended practice for use by engineers and technicians in the public and private sectors. This method was to (1) be based on Superpave mix design methodology, (2) include a suite of performance tests to assess whether a WMA mix design will provide satisfactory field service, and (3) be applicable to any WMA technology used to lower mixing and compaction temperatures [4].

Table 3. Development of WMA (NCHRP Report)

Project Number	Report Number	Effective Date	Completion Date
NCHRP 9-43	NCHRP-691 NCHRP-714	3/22/2007	1/31/2011
NCHRP 9-47	*	3/31/2008	1/8/2009
NCHRP 9-47A	NCHRP-779	7/13/2009	3/10/2014
NCHRP 9-49	NCHRP-763	7/26/2010	9/30/2013
NCHRP 9-49A	*	4/29/2011	7/28/2016
NCHRP 9-52	*	6/1/2012	2/28/2015
NCHRP 9-53	*	6/1/2012	10/31/2014

Note- '*' Information is not available

NCHRP 9-47: This project was started in 31th march 2008 and it has completed on 8th January 2009. The total fund for this project was $79,000. Objective of this project were to (1) establish relationships among engineering properties of WMA binders and mixes and the field performance of pavements constructed with WMA technologies, (2) determine relative measures of performance between WMA and conventional HMA pavements, (3) compare production and lay down practices and costs between WMA and HMA pavements, and (4) provide relative emissions measurement of WMA technologies as compared to conventional HMA technologies. Project deliverables shall include (1) recommended modifications to the preliminary WMA mix design and analysis procedure under development in NCHRP Project 9-43, (2) a protocol for laboratory evaluation of WMA performance, (3) guidelines for WMA production and construction, and (4) an updated emissions measurement protocol.

NCHRP 9-47A: This project was started in 13th July 2009 and it has completed on 10th March 2014. The total fund for this project was $1,121,000. The objectives of this project were to (1) establish relationships among engineering properties of WMA binders and mixes and the field performance of pavements constructed with WMA technologies, (2) determine relative measures of performance between WMA and conventional HMA pavements, (3) compare production and lay down practices between WMA and HMA pavements (including necessary plant adjustments to optimize plant operations when producing WMA), and (4) provide relative emissions measurement of WMA technologies as compared to conventional HMA technologies [12].

NCHRP 9-49: This project was started in 26th July 20010 and it has completed on 30th September 2013. The total fund for this project was $450,000. The objectives of this research were to (1) assess whether WMA technologies adversely affect the moisture susceptibility of flexible pavements and (2) develop guidelines for identifying and limiting moisture susceptibility in WMA pavements.

NCHRP 9-49A: This project was started in 29th April 20011 and it will complete on 28th July 2016. The total fund for this project was $960,925. The objectives of this research are to (1) identify the material and engineering properties of WMA pavements that are significant determinants of their long-term field performance and (2) propose best practices for the use of WMA technologies. In this research, the phrase "long-term" is defined as a minimum of 4 years after construction. The performance of 17 WMA pavements (with one to three WMA technologies) and their HMA control sections in the following states are being monitored over the life of Project 9-49A [13].

NCHRP 9-52: This project was started in 1ST June 2012 and it will complete on 28th February 2015. The total fund for this project was $800,000. The objective of this research is to develop procedures and associated criteria for short-term laboratory conditioning of asphalt mixtures for mix design and performance testing to simulate the effects of (1) plant mixing and processing to the point of loading in the transport truck and (2) the initial period of field performance. These procedures and criteria shall be representative of the asphalt production facilities and production temperatures (approximately 240 to 340°F) currently found for asphalt mixtures [14].

NCHRP 9-53: This project was started in 1ST June 2012 and it will complete on 31th October 2014. The total fund for this project was $700,000. The objectives of this research are to (1) determine the key properties of foamed asphalt binders that significantly influence the performance of asphalt mixtures and (2) develop laboratory protocols for foaming of asphalt binders and laboratory mixing procedures [14].

1.10 India

The first field trial of warm mix in India was laid over a 500 meter section of road at Bawana industrial area owned by the Delhi State Infrastructure Development Corporation (DSIDC). The trial was placed using a surfactant based chemical warm mix additive and crumb rubber modified bitumen (CRMB) on August 10th, 2009. The warm mix section was 11 meters wide and 40mm thick bituminous course mix. The field evaluations were carried out on March 5th and 6th, 2012 [15 &16].

The second project evaluated was placed on April 7th, 2011 on State Highway (SH) 5 in Gujarat between Godhra and Halol. The warm mix section was one kilometer in length, 7.5 meters wide and 40mm thick in the bituminous course. Following the construction of the pavement, field evaluations were carried out on May 11th and 12th, 2012.

The WMA additive supplier is mainly two Shell and MWV (MeadWestvaco). The MWV provide Evotherm and Shell provides Thiopave. Evotherm is accredited by IRC, approved by BRO and evaluation by CRRI & IIT-M. Several project completed and these have established the performance benefits of Evotherm. MeadWestvaco say that since 2009 roughly 50 lane Km of Evotherm warm mix pavement have been executed on Indian highway.

Shell Thiopave is selected as a WMA additive that can also significantly improve the mechanical performance of asphalt pavement. The IRC (Indian Roads Congress) has also issued accreditation certificate to Shell.

The trial section was constructed in September 2010 on National Highway No. 3 near Nashik by Ashoka Buildcon Ltd under the guidance of AHRC and Shell Engineers into three section as under :-

- Thiopave + Thiopave DBM layer (km 429/595 to km 429/705)
- Thiopave + Conventional DBM layer (km 429/495 to km 429/595)
- Conventional + Conventional DBM layer (km 429/385 to km 429/495)

Ashoka Buildcon has been also using WMA technologies toll way work NH-3 from Pimpalgoan Nasik Gonde (380 TO 440 Km).

Some of the roads which are constructed in India by warm mix technologies are given in tabular form in Table 4.

Table 4 WMA construction in India on public roads

No.	Date	Classification (location)	Length (Km)	Volume	PG -Grade	WMA Additive
1	10-08-2009	Bawana industrial area	0.500	--	CRMB-60	--
2	17-01-2011	NH-10	--	--	CRMB	EVOTHERM
3	07-04-2011	SH-5 (Gujarat)	1.000	--	VG-30	--
4	Sep 2010	NH-3	210.00	--	--	Thiopave

India has started working on different parameter of WMA in various projects. Some of the project is completed and some of project is in active state are given in Table 5.

Table 5 WMA Project in India (IRC Highway Research Board)

Project Title	Conducted By	Date of start	Completion Date
Laboratory Evaluation of Warm Mix Additives	CRRI, New Delhi	July 2009	April 2010
Development of Low Energy (Warm) PMB and CRMB mixes.	NIT- Surathkal	April 2011	March 2013
Laboratory Investigation of Warm Mix Asphalt. Using Chemicals and Comparisons with Hot Mix Asphalt (Bituminous Concrete)	CRRI & Yala Construction, New Delhi	June 2011	March 2012
Study on Use of Emulsion Based Warm Mix Asphalt Using Half Warm Aggregates for Bituminous Road Construction.	CRRI, New Delhi	Oct 2012	Dec 2014
Development of Emulsion Based Half Warm Mix for Road Construction	CRRI, New Delhi	April 2012	March 2014
Development of Low Energy Asphalts Mixes Using Foam Bitumen and Bitumen Emulsion	CRRI, New Delhi	Aug 2012	March 2014
Development of specification of WMA for Indian conditions	IIT-Roorkee & CRRI-New Delhi	May 2012	Continue

2. ADVANTAGE OF WARM MIX ASPHALT OVER HMA

Significantly lower mixing and compaction temperature: mixing temperature for HMA is generally 140°C to 160°C but for WMA is 100°C to 140°C and it has been observed that average reduction of temperature for WMA is 20°C to 30°C with compare of conventional HMA (NCHRP 691, 2011) [1].

Energy consumption, thus lowering the fuel/energy cost: it has been observed that 20 to 35% reduction of energy in plant mix it means 1.5 to 2 litre of fuel per tonne of materials saving. But it depends on the type of plant and WMT and temperature of mixing as well as moisture present in aggregate [17].

Less aging of binder: at high temperature the aging is more and at less temperature the aging less so WMA have less mixing and compaction temperature so it has less aging. The aging index is more it means life of pavement is more [18].

Reduced thermal segregation in the mixing: the rate of cooling is less for WMA compare with HMA so the thermal segregation gets reduced. Thermal segregation significantly impact on density of the surface of pavement and density significantly impacts on roadway performance. An increase of 1% air voids translates to about 300% increase in permeability and 10% reduction in pavement life (MOBA PAVE-IR, 2011, TRAC 2001).

Decreased emission /odors from mixing plant and during placement: the warm mix asphalt European practice in February 2008 has been observed that there is average reduction on CO_2 & SO_2 30-40%, VOC- 50%, CO-10-30%, NO_x- 60-70%, Dust -20-25% and Fuel saving 11-35%. The odors from mixing plant and during placement get reduced compare of HMA [19].

Extending paving season: WMA can also help to shorten project delivery by facilitating longer paving seasons. Warm-mix technologies offer the potential to extend the paving season in colder climates. This is possible because of three factors. First, WMA additives or processes improve compaction at a given temperature. Second, WMA is compactable at lower temperatures than HMA. Third, the rate of cooling is driven by the difference in temperature between the asphalt mixture and ambient air, so that a mixture produced at a lower temperature will cool at a slower rate.

Extended mix haul distance: The rate of cooling of mix is less for WMA with the relative of HMA so the haul distance is more for WMA. It has been observed that with the different WMT the average haul times of 1 to 8 hr produce no major difference in aging for given binder or between binder types (Howard and Isaac L, 2014) [20].

Improved working condition: In the WMA construction the asphalt fumes is less compare with HMA. In different countries have different measurement parameters and equipment. German forum states that there were 30 to 50% reduction in asphalt polycyclic aromatic hydrocarbon (PAHs) and aerosol/fumes.

Diminished concentration: Easier permitting for plant: MWA prepare in HMA plant which is existing with no modification, slightly modification or with modification depends on the WMT.
Site in urban areas: Easier permitting for a plant site in urban areas, due to reduction in noise, dust and emission.

Increased usage of RAP: In Europe, WMA has been used 50% RAP successfully in pavement. In U.S.A in some project they have used 50% RAP but generally they used 20% RAP or less in WMA (Zhao et. al. 2012) [21].

3. REVIEW OF WMA IN INDIA

Evaluation of field performance of warm-mix asphalt pavements was done by Central Road Research Institute (CRRI) on two section, Bawana industrial area roads and SH-5. After 30 to 31 month of construction, the field study was conducted and it was found that Benkelman beam deflection and Bump integrator values are similar for WMA and HMA. The core samples taken from field and tested in laboratory revealed that Marshall Stability value of WMA is more than HMA, which is due to improved density and less oxidation of mixes. Haul time is same for both WMA and HMA and it was observed that rate of cooling is less for WMA compared with HMA.
Behl et al. (2013): Proposed that WMA can be produced 20°C to 30°C lower than conventional HMA. In this paper it is observed that viscosity and dynamic modulus improve after mixing WMA additive Sasobit as shown in Table 6 and Figure 1 respectively [16].

Table 6. Rotational viscosity of VG-30 bitumen with different content of Sasobit

Bituminous binder	Viscosity at 100ºC (cP)	Viscosity at 120ºC (cP)	Viscosity at 130ºC (cP)	Viscosity at 150ºC (cP)
VG-30	2525	650	425	150
2% Sasobit	2625	600	375	125
3% Sasobit	2800	575	350	125
4% Sasobit	2975	550	300	95

Viscosity decreases with increase of temperature at 100°C the viscosity increase with increases of amount of Sasobit. The rutting and fatigue resistance is better for WMA and the stiffness of binder increases between 40°C and 88°C [16].

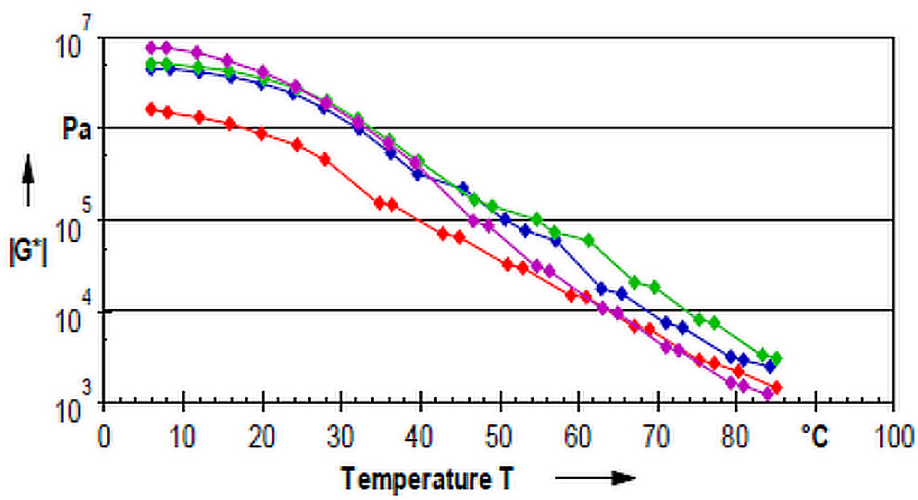

Figure 1. Complex modulus of bituminous binder at different temperature

Jain et al. (2014), found that polymer modified warm mix asphalt has better performance than polymer modified hot mix asphalt. In this paper organic surfactant warm mix additive was taken and the optimum additive content was found 2% by bitumen weight. To find the mixing, compaction and rolling temperature authors conducted viscosity test at different temperature and found that at 2% WMA additive the reduction of temperature is 15°C to 25°C.Creep modulus, resilient modulus, TSR and fatigue (four point bending beam fatigue) tests were conducted and was found that it give better performance of polymer modified warm mix asphalt is better than that of polymer modified hot mix asphalt. The rutting of polymer modified warm mix asphalt was found lower than polymer modified hot mix asphalt [22].

Patel et al. (2014): Marshall Test was conducted on conventional mix to find the optimum bitumen content and it was 5.5%. For warm mix 1.5%, 2% and 2.5% Rediset by bitumen content (5.5%) was added at different temperatures of 110°C, 120°C and 130°C and Marshall Tests were conducted. Authors found that stability of WMA at 120°C is more than the conventional mix [23].

Guar et al. (2013): Used synthetic wax that has mix with 80/100 grade bitumen. The optimum compaction temperature has found by Marshall Test which has conducted at 105°C, 125°C and 155°C with different bitumen content. It has found that at 110°C the WMA gives better stability and resilient modulus. The WMA has more resistance to moisture susceptibility than HMA [24].

Manjunath et al. (2014): Proposed that warm mix additive Evotherm and Cecabase RT gives better Marshall Stability value as compared to conventional HMA. In this paper two grades of bituminous concrete were taken (grade 1 & grade 2), for grade 1 the optimum bitumen content was 5.7% at 130 °C for WMA and at 160°C for HMA. For grade 2 the optimum bitumen content was 6.4% at 130°C for WMA and at 160°C for HMA. It is observed that WMA gives more bulk density and Marshall Stability values after adding of WMA additive 0.3% and 0.4% by weight of bitumen [25].

4. CONCLUSIONS

Warm mix asphalt (WMA) technology, has developed in Europe, and is gaining strong interest worldwide. Most of the technology was developed in U.S.A. and there are 30 different technologies available; out of which two- third technologies are based on foaming of bitumen.

WMA is gaining popularity worldwide mainly due to reduction in emission and fuel consumption when compared with conventional HMA.

WMA technologies include reduction in fuel usage and emissions in abide of sustainable development, improved field compaction, which can provide better working conditions, longer haul distances and cool weather pavement.

Laboratory and field studies conducted by CRRI, New Delhi have found better performance of WMA than the conventional HMA.

The major research in India the main research is going on organic and chemical warm mix additive because these additives do not require measure modification in the plant because the additive can be blend with bitumen. The foaming technology requires major modification in the plant but the construction cost is less as compare to non-foaming (chemical and organic) technologies. In U.S.A the Plant Foaming is 88.1%, use of Chemical Additives is 9.6%, and Additive Foaming is 2.1% and Organic Additives 0.2%.

REFERENCES

[1] NCHRP-691, Mix Design Practices for Warm Mix Asphalt, Available online at http://www.trb.org/main/blurbs/165013.aspx Accessed May 25, 2014.
[2] European Asphalt Pavement Association (EAPA), Driving Ahead with Sustainable Asphalt Roads, Warm Mix Asphalt. Available online at http://www.eapa.org/promo.php?c=202. Accesses on date 10/10/2014.

[3] NCHRP-9-47, Properties and Performance of Warm Mix Asphalt Technologies, Available online at http://www.trb.org/Main/Blurbs/171480.aspx Accessed August 25, 2015.
[4] NCHRP Project 9-43 Draft Standard Practice, "Design of Warm-Mix Asphalt (WMA)", June 2008.
[5] NCHRP-691, Mix Design Practices for Warm Mix Asphalt, Available online at http://www.trb.org/main/blurbs/165013.aspx Accessed May 25, 2014.
[6] Davidson J.K., Tighe S., Croteau J-M, "Paving the Way to Environmentally Friendly Pavements Through Innovative Solutions", Proceedings, Canadian Technical Asphalt Association, 51, 97-121, 2006.
[7] Everete Crews and Wenyuan Huang, "The introduction of Evotherm warm mix asphalt technology", MeadWestvaco Corporation, ppt for China. 2007.
[8] Zhuohui Tao , Wenyuan Huang , Qunle Du and Jinhai Yan, "Warm Mix Asphalt Technology Applied at Low AirTemperature in China" Road Materials and Pavement Design, pages 337 to 347, ICAM 2009.
[9] Yongjoo Kim, Jaejun Lee, Cheolmin Baek, Sunglin Yang, Sooahn Kwon, and Youngchan Suh, "Performance Evaluation of Warm- and Hot-Mix Asphalt Mixtures Based on Laboratory and Accelerated Pavement Tests" Hindawi Publishing Corporation Advances in Materials Science and Engineering Volume 2012, Article ID 901658, 9 pages doi:10.1155/2012/901658.
[10] Wynand Nortjè and Anthony Lewis, "Full scale implementation of warm mix asphalt in south africa" 10th conference on asphalt pavements for Southern Africa, 2010.
[11] Rosangela Motta, Liedi Bernucci, Decio Souza, Yves Brosseaud, José Fernando Leal, "Field performance and laboratory evaluation of warm mix asphalt produced with rubberized bitumen" ee-tpc-345, 2013.
[12] NCHRP 9-47, Engineering properties, emissions, and field performance of warm mix asphalt technologies interim report prepared for national cooperative highway research program (NCHRP) transportation research board of the national academies, 2008.
[13] NCHRP-763, Evaluation of the Moisture Susceptibility of WMA Technologies, Available online at http://www.trb.org/main/blurbs/170340.aspx Accessed August 5, 2014.
[14] NCHRP-714, Special Mixture Design Considerations and Methods for Warm-Mix Asphalt: A Supplement to NCHRP Report 673: A Manual for Design of Hot-Mix Asphalt with Commentary, Available online at http://www.trb.org/main/blurbs/166517.aspx Accessed July 25, 2014.
[15] Bhel, A., Chandra, S. and Aggarwal, V.K. (2013). "Rheological Characterization of Bituminous Binder containing Wax based Warm Mix Asphalt Additive", IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), Volume 9, Issue 1, 16-22.
[16] Bhel, A., Kumar G., Sharma G., and Jain P.K. (2013). "Evaluation of field performance of warm-mix asphalt pavements in India", Procedia - Social and Behavioral Sciences, Issue 104 158 – 167.
[17] Romier, Audeon, David, Martineau, and Olard, "Evaluation of Low-Temperature Cracking Performance of Warm-Mix Asphalt Mixtures" Transportation Research Record: Journal of the Transportation Research Board, No. 2294, Transportation Research Board of the National Academies, Washington, D.C., 2012, pp. 81–88. DOI: 10.3141/2294-09.
[18] Mogawer, Austerman, and Bahia, "Evaluating the Effect of Warm-Mix Asphalt Technologies on Moisture Characteristics of Asphalt Binders and Mixtures" Transportation Research Record: Journal of the Transportation Research Board,No. 2209, Transportation Research Board of the National Academies, Washington, D.C., 2011, pp. 52–60. DOI: 10.3141/2209-07.
[19] D'Angelo, J., et al. (2008). "Warm-mix asphalt: European practice." International Technology Scanning Program, Publication No., FHWA-PL-08-007, U.S. Dept. of Transportation, Federal Highway Administration, Washington, DC, 5–10.
[20] Howard & Isaac L, "Evaluation of Low-Temperature cracking Performance of Warm-Mix Asphalt Mixtures" Transportation Research Record: Journal of the Transportation Research Board Issue Number: 2408 Transportation Research Board ISSN: 0361-1981.
[21] S. Zhao, B. Huang, and X. Shu, "Laboratory Performance Evaluation of Warm-Mix Asphalt Containing High Percentages of Reclaimed Asphalt Pavement" Transportation Research Record: Journal of the Transportation Research Board, No. 2294, Transportation Research Board of the National Academies, Washington, D.C., 2012, pp. 98–105. DOI: 10.3141/2294-11.
[22] P.K. Jain, Uma Devii Rongali, Anita Chourasiya and Munshi Ramizraja M., "Laboratory Performance of Polymer Modified Warm Mix Asphalt",Paper No. 608, Journal of the Indian Roads Congress, January-March 2014.

[23] Mitul Patel, Vikas Patel, Devendra K. Patel and C.B. Mishra, "Evaluating Properties of VG 30 Paving Mix With and Without Warm Mix Additive", International Journal of Innovative Research in Science, Engineering and Technology,ISSN:2319-8753, vol.3, issue 6, June 2014

[24] Gaur, Arun and Bose, Sunil, "Performance of warm mix asphalt for Indian conditions" Indian Highways volume 41, issue number 9.

[25] Manjunath K.R , Dheeraj Kumar N , Thippeswamy G.S," Performance and Evaluation on Marshall Stability Properties of Warm Mix Asphalt Using Evotherm and Cecabase Rt®-A Chemical Additive", International Journal of Engineering Trends and Technology (IJETT) – Volume 12 Number 8 - Jun 2014.

AUTHORS

Rajiv Kumar received the B.Tech degree in civil engineering from school of engineering (CUSAT), in 2010 and M-Tech degree in Transportation engineering from I.I.T. Guwahati in 2012. In 2012, he joined the department of civil engineering, TCOER, Pune, as an Assistant professor and in 2013 he joined VIIT, Pune, as assistant professor. He is currently pursuing PhD from I.I.T.Roorkee. His PhD research on project sponsored by DST "Development of specification of WMA for Indian conditions".

Dr. Satish Chandra received the B.E., M.Tech and Ph.D degree in civil engineering from the University of Roorkee, Roorkee, in 1983, 1985 and 1994, respectively.In 1985, he joined the Department of Civil Engineering, University of Roorkee, as a Lecturer, and in 1996 became an Assistant Professor University of Roorkee, in 2001 he became Associate Professor in I.I.T. Roorkee and in 2006 he became Professor in I.I.T. Roorkee. Since January 2016, he became the Director of CRRI, New Delhi. His current research interests include Transportation, Traffic Engineering, and Pavement Materials.