HBRP PUBLICATION

Journal of Advances in Civil Engineering and Management
Volume 2 Issue 3

The Study of Effects of the Overheated Bitumen on the Binder Content and the Marshall Properties of the Asphalt Concrete

Samir Baidya[1]*, Gautam Bir Singh Tamrakar[2]
[1]Senior Engineer, Swachchhanda Nirman Sewa (Pvt.) Ltd, Nepal.
[2]Professor, Department of Civil Engineering, Institute of Engineering, Pulchowk Campus, Tribhuvan University, Nepal.
Corresponding Author
E-mail Id:-*samirbaidya2013@gmail.com*

Abstract

Road Transport is the major mode of transportation in context of Nepal due to its difficult geographical and geological terrain and also due to the need of huge cost of construction of the infrastructures for the other modes of transportation. The heating of the binder may cause oxidation and stiffening of the binder, hardening of the binder, increase of viscosity and softening temperature. It is necessary to study the influence of overheating on the properties of the bitumen and its impact of the strength of the asphalt concrete. The bitumen binder is heated at different temperatures 185^0c, 195^0c, 205^0c, 215^0c, and 225^0c for 3-4 hours in an oven and mix design is prepared for each sample at respective temperatures. The study shows that the Marshall Stability value goes on decreasing at increased temperature. Similarly, the OBC and VFB increases as the bitumen becomes less viscous when heated at higher temperature and the aggregate minerals are coated thickly and more voids is filled. The penetration of the overheated bitumen decreases with increase in temperature and the softening point and viscosity of the overheated bitumen also increases as the bitumen is overheated it loses the volatile materials and oxide with oxygen to become stiffer. The Penetration index of the bitumen is found to be more at 215^0C. So, the properties of the bitumen changes at higher temperature and will become more brittle and the asphalt mix will be more prone to cracking.

Keywords:-*Overheated Bitumen, Marshall Stability, OBC, Air Voids, Penetration Index*

INTRODUCTION

Road Transport is the major mode of transportation in context of Nepal due to its difficult geographical and geological terrain and also due to the need of huge cost of construction of the infrastructures for the other modes of transportation. The road network provides the greater utility in transport in hauling the commodities and passengers over short and long distances. In context of Nepal, there is a huge construction project undergoing in the development, upgrading of the highways and feeder roads connecting each and every places all around the country. There are various types of flexible pavement constructed over the country depending upon the traffic volume, durability, design life, maintenance, cost of construction etc. Recently the government has been upgrading the major highways and the feeder roads to the asphalt concrete, so the construction of the asphalt concrete has been widely increased throughout the country. Since the asphalt concrete is more costly than other types of flexible pavement, various factors should be taken into the consideration during the construction work.

Asphalt concrete is the composite material consisting of the coarse, fine and the mineral filler binding with the bituminous mixture commonly used for the paving of

the road surface, highways, runways, taxiways and parking lots. The AC shall provide the waterproof surface with good resistance against the deformation, rutting and will provide good smooth surface with good skid resistance. For the good AC it should have sufficient resistance to plastic deformation and cracking when subjected to the expected traffic loading, should have acceptable grading and strength of aggregate with sufficient air voids to avoid bleeding and should be workable for efficient laying and compaction. The mineral aggregate comprises the huge bulk of the composite mixture about 90~ 95 % of the HMA mix by weight and hence provide the significant role in the engineering properties of the mixture. The properties of AC are mainly influenced by the quality and the strength of the aggregate and the bitumen as it comprises.

In context of Nepal the temperature variation ranges from cold in the mountainous to the hot in Terai areas. For laying the asphalt works on the cold region the temperature drop is quick so the temperature prior to lying of asphalt concrete should be checked and should not drop below 145^0c. So, if the transportation distance is long the asphalt concrete may need to be heated beyond the temperature of 165^0c. It is necessary to have the information regarding the effect of overheating in the properties of the asphalt concrete. Too high temperature acting on an asphalt mixture is destructive, mainly to bituminous binders, which can impact pavement durability. The heating of the binder may cause oxidation and stiffening of the binder, hardening of the binder, increase of viscosity and softening temperature. The rheological properties of the binder will be changed if the binder is heated beyond the certain limit temperatures. The environmental factors such as temperature, air, and rain water can have a profound effect on the durability of asphalt concrete mixtures. In mild climatic conditions, the deterioration may be due to traffic loading, and the resultant distress manifests as fatigue cracking, rutting and raveling. However, in a severe climate the rain water and the moisture content are key elements in the degradation of asphalt concrete pavements. The in percolated moisture through the crack and fissures at the surface from the underneath layer of base and sub base will cause the loss of adhesion at the bitumen aggregate interface which is also called stripping of the asphalt concrete. The damage of the asphalt pavement due to the water may be due to various causes as poor gradation, gap graded aggregates, excess void contents, binder type, traffic loadings, material type and other several factors. In this study the effects of overheating the binder to the strength of asphalt concrete as well as the effect in the void contents and the binder content of the asphalt concrete will be studied.

PROBLEM STATEMENT

The overheating of the bitumen will change the rheological properties of the bitumen and makes it stiffer, less viscous and harder. In context of Nepal the bitumen are heated in the boiler prior to the pavement works and in the bitumen distributor for the flexible pavement works (surface dressing, penetration macadam, otta seal, priming works etc.). Since the bitumen are more often heated in higher temperature and are frequently heated, the properties of the bitumen will be changed and will have serious impact on the strength of the flexible pavement. At higher temperature, the asphalt softens and will cause the permanent deformation of the pavement. As the higher temperature hardens the bitumen, the development of cracks is more prone when the load is applied on it and will be more susceptible to the water damage. So, it is necessary to study the influence of overheating on the properties of the bitumen and its impact of the strength of the asphalt concrete.

OBJECTIVES

In order to study the effects of the overheating on the properties of the bitumen and its effect on the strength and binder content of the asphalt concrete, the study has been conducted to achieve the following objectives:

1. To study the effects of heating temperature on the properties of the bitumen.
2. To find out the optimum binder content at various temperature with overheated bitumen on the asphalt concrete.
3. To study the effects of the overheated bitumen on the Marshall Properties of the asphalt concrete.

LITERATURE REVIEW

Overheating of the bitumen will change the durability of the asphalt pavement and also change in the visco elastic properties of the binder. The penetration test of the bitumen gives the binder consistency in average operating temperature at 25^0c and indicates the degree of hardness, the softening point and viscosity test gives the binder consistency in a high operating temperature and indicates the degree of flow resistance. Selection of Bitumen grades should be based on high and low pavement temperatures as VG 30 can be used in high temperature zones as it has good thermal susceptibility so, use of VG-10 would not provide good rutting resistance. The bitumen content of the asphalt mixture varies upon the gradation types, specific gravity and other aggregate properties. Generally, binder and the wearing course of the asphalt concrete is carried out in major highways of Nepal.

Michal Sarnowski presented the study on the impact of elevated process temperatures exceeding 240^0c on the properties of non-modified bitumens and SBS polymer modified bitumens heated at different temperatures of 200^0c, 250^0c, 300^0c, for 1 hour and the asphalt mixtures were heated at the same temperatures. It was concluded that the SBS polymer modified bitumen was higher overheating sensitivity and when the bitumen were heated above the temperature of Overheating Degradation index, loss of viscoelastic properties occur which causes loss of resistance to fatigue cracking[1].

Senja Rum Harnaeni concluded in the study that the temperature changes influence bitumen stiffness, asphalt mix stiffness and fatigue life asphalt mix. The higher the temperature, the lower the bitumen stiffness and asphalt mix stiffness and the higher the fatigue life asphalt mix. At the same temperature, asphalt mix stiffness of dense graded mixture is higher than gap graded mixture [2].

The bitumen in the asphalt mix coats all the mineral aggregates and holds all the aggregates in position. The load is transferred by the aggregate mass through the contact points. So, the optimum binder content is necessary for the stability of the mix but when the binder content exceeds the OBC then the air voids starts to fill up with the excess bitumen and the contact of aggregate may start to lose resulting the load transfer by the hydrostatic pressure through the bitumen reducing the strength of the mix [3].

The properties of the aggregate used in the construction of road pavement differ in their composition, shape and the physical properties. Aggregates found in the nature are heterogeneous mix comprising the limestones, granites, gravels having composed of variety of minerals. The aggregate composition and type have a much stronger influence on the adhesion and bonding of the asphalt to the surface than does the asphalt [4]. A well-graded, crushed aggregate should be used to provide the highest-quality asphalt concrete. Uncrushed aggregates such as natural sands and uncrushed gravels produce mixtures with lower stability and

decreased durability, whereas a well-graded aggregate fits together more tightly during compaction, resulting in a lower required asphalt content and improved stability and durability [5]. Randolph C. Ahlrich has found that the percentage of crushed coarse particle decreased the rutting potential of the HMA mixtures increased and the increase in the natural sand content has an adverse effect on the laboratory permanent deformation properties [6].

METHODOLOGY

Material

The materials that are used for the study comprises of the coarse aggregate, fine aggregate, mineral filler and the bitumen of VG 30. The sampling of the material from the quarry meeting the required specification has been discussed below as:

Selection of Aggregate

The aggregate for the study comprises the coarse and fine aggregate which have been collected from Tikabhairav Quarry. Aggregate is the major component of the asphalt mix which transfers the wheel load to the subsequent layers so, it should be well graded, durable and strong to make the pavement act as a monolithic layer. The selection of the aggregate with their physical tests as per specification of Standard Specification for Road and Bridge works, 2073 published by DoR has been described in below section.

Coarse Aggregate

Coarse aggregate is the particle that is retained by 4.75 mm sieve and is entirely crushed, clean and free from all deleterious materials. The physical test conducted for the coarse aggregate has been listed below:

Table 1:-*Physical tests for Coarse aggregate*

S. No.	Test Descriptions	Specification Limit	Test Result
1	Los Angeles Abrasion	Maximum 30%	21.08%
2	Aggregate Impact Value	Maximum 24%	12.02%
3	Water Absorption Test	Maximum 2%	1.5%
4	Specific Gravity Test		2.67
5	Stripping Test	More than 95%	>95%
6	Flakiness Index	Maximum 25%	22.67%
7	Elongation Index	Maximum 25%	23.85%

Aggregate Gradation

The gradation of the aggregate is the major factor that should be considered for the design of any asphalt pavement in order to maintain the required air voids in the asphalt aggregate mixture. Firstly, the gradation of each aggregate types is carried out individually and is blended in the required proportion so as to meet the required specification.

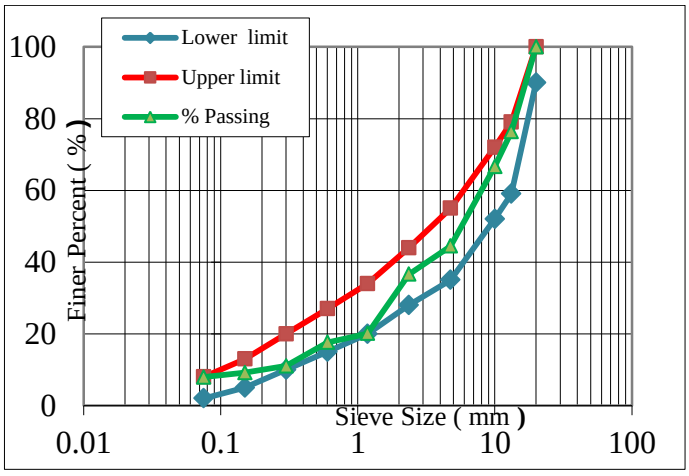

Fig.1:-*Combined gradation curve*

Bitumen

The bitumen used for the study is Viscosity Grade VG 30 of Durapave of Indian oil. The different tests of bitumen have been carried out which has been summed up in Table 2 below:

Table 2:-*Standard tests of bitumen*

S.N	Characteristics	Value
i	Penetration at 25°C, 100 g, 5 s, 0.1 mm, Min	59.33
ii	Absolute viscosity at 60 °C, Poises	2522
iii	Kinematic Viscosity at 135 °C Cst	359
iv	Softening point (R & B) °C,	48.6
v	Solubility in Trichloroethylene	99.5
vi	Flash Point, Cleveland open cup, °C	280
vii	Fire Point °C	318
viii	Loss on Heating for 5 hours at 163 °C	0.263%
ix	Ductility at 25 °C, cm	>100
x	Specific gravity	1.032

Mix Design

The mix design of the asphalt concrete is carried out by testing the five different asphalt contents for a single selected aggregate gradation to obtain the optimum binder content considering the various volumetric and the strength using the Marshall method. For determining the design asphalt content of the mix the series of test specimens is prepared with the increment of asphalt content by 0.5% in order to obtain the well defined relationship of the data curves.

The optimum binder content of the bituminous mix is calculated by taking the average value of the bitumen content at maximum stability, maximum density and 4% air voids which is shown in table below:

Table 3:-*Determination of OBC*

S.N	Description	Binder Content (%)
1	Bitumen Content at Maximum Density	5.90
2	Bitumen Content at Maximum Stability	5.10
3	Bitumen Content at 4% Air Voids	4.67
4	Average Bitumen Content	5.22

RESULT AND ANALYSIS

Overheating of the Bitumen

The bitumen is heated in the hot air oven at constant temperature of 185^0C, 195^0C, 205^0C, 215^0C and 225^0C for about 3-4 hours and the physical properties of all the heated bitumen samples were tested. When the bitumen is heated at higher temperature the rheological properties of the bitumen get changed and the ageing of the bitumen occurs which has direct effect on the strength of bituminous mixes.

Effect on Properties of Bitumen

The various properties as penetration, softening point and absolute viscosity of different samples of bitumen heated at various temperatures 185^0C, 195^0C, 205^0C, 215^0C and 225^0C were tested and the results obtained are interpreted in the graph below.

The penetration value of the bitumen decreases with the increase in the overheating temperature of bitumen. The results are shown in graph below:

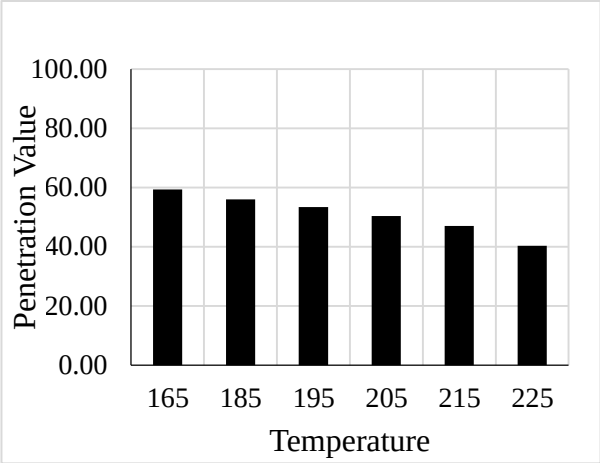

Fig.2:-*Penetration Value vs. Overheating Temperature of Bitumen*

The softening point of the bitumen increases with increasing temperature. The results are shown below:

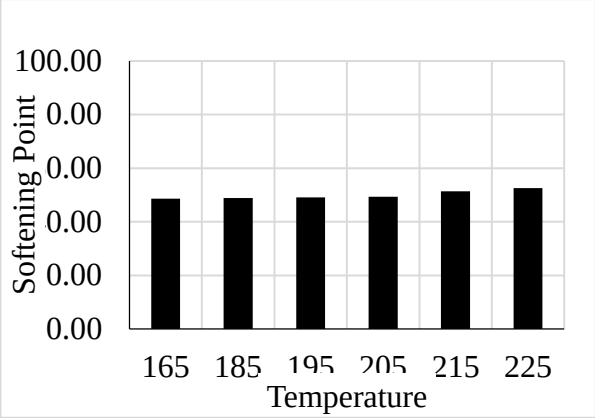

Fig.3:-*Softening vs. Overheating Temperature of Bitumen*

The absolute viscosity of the bitumen increases with increasing temperature of the bitumen. We can see that when the bitumen is overheated it is more viscous because of the loss of the volatile materials and the occurrence of oxidation and ageing which makes bitumen stiffer. The results are shown below:

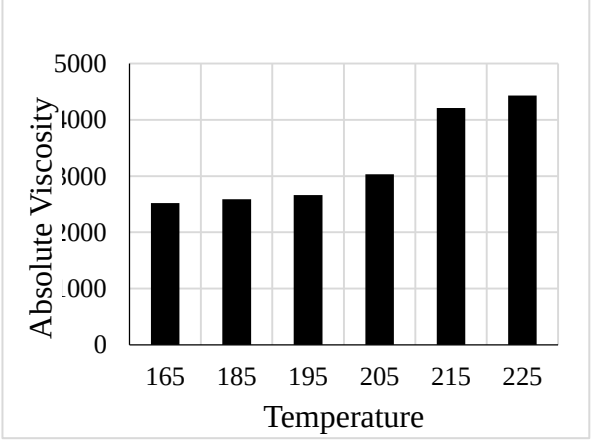

Fig.4:-*Absolute Viscosity vs. Overheating Temperature of Bitumen*

Penetration Index of the bitumen is the quantitative measure of the bitumen to the given temperature. It should have the value ranging from -2 to +2. When PI is low, the bitumen becomes very brittle at lower temperature and when PI is high it has more resistance to permanent deformation. As the result shows that the PI value decreases with increase in temperature but at temperature 215^0C the PI value increases. Hence when the bitumen is heated beyond the temperature the brittleness of the asphalt concrete increases which will result in cracking and low durability.

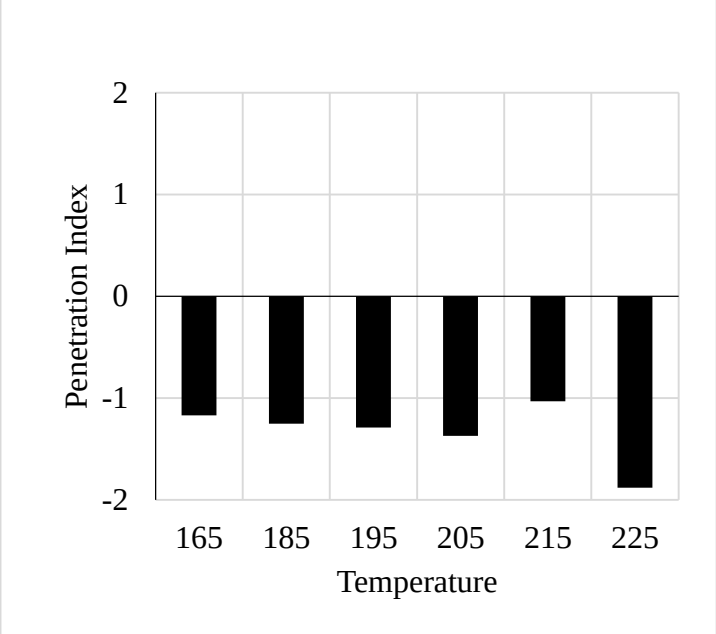

Fig.5:-*Penetration Index vs. Overheating Temperature of Bitumen*

Effect on Properties of Asphalt Concrete

The Marshall mix design is carried out for each sample of bitumen heated at different temperatures 185^0C, 195^0C, 205^0C, 215^0C and 225^0C to find out the optimum binder content and the change in other volumetric measures. For each variation in the temperature the optimum binder content is calculated and the corresponding values of VMA, VTM, VFB, Marshall stability, flow and density is computed.

Maximum Density

The density of the asphalt mix at higher temperature continuously increases sharply and after certain binder content the curve gently increases. So considering the binder content at maximum density, maximum stability and 4% air voids.

The Marshall Stability value decreases with the increase in the temperature of the overheated bitumen. When the bitumen is overheated the bitumen will be less viscous and hence makes sufficient coating of the aggregate and the filling the excess voids in the mix. At the same time the rheological properties of the bitumen also changes due to which durability of the mix decreases. So, the bulk density, OBC, flow value and VFB increases with the increases of temperature and VTM and VMA decreases with the increase in the temperature of bitumen which has been shown in graph below:

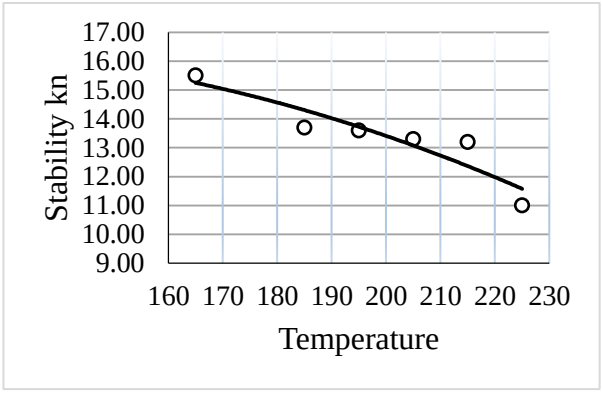

Fig.6:-*Stability vs. Overheating Temperature of Bitumen*

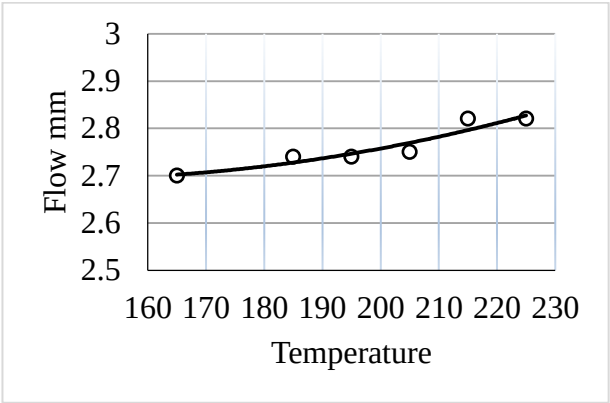

Fig.7:-*Flow vs. Overheating Temperature of Bitumen*

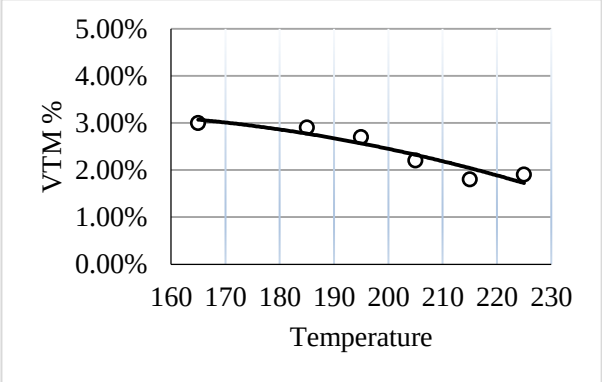

Fig.8:-*Air Voids vs. Overheating Temperature of Bitumen*

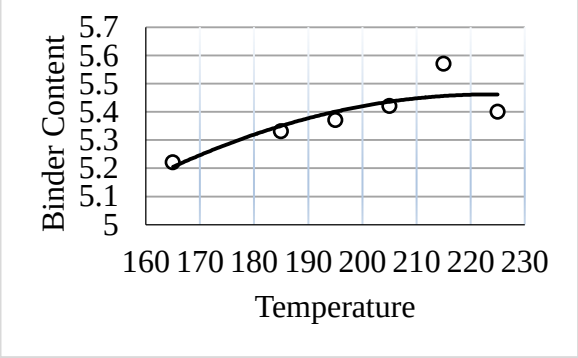

Fig.9:-*OBC vs. Overheating Temperature of Bitumen*

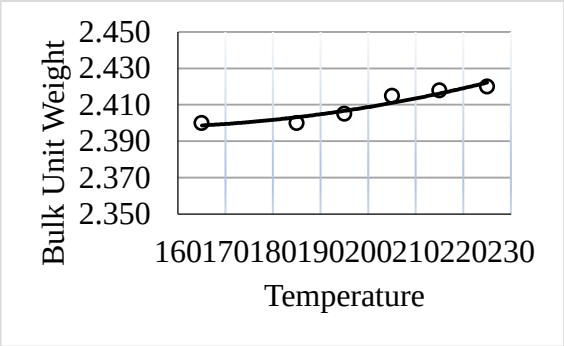

Fig.10:-*Bulk Unit Weight vs. Overheating Temperature of Bitumen*

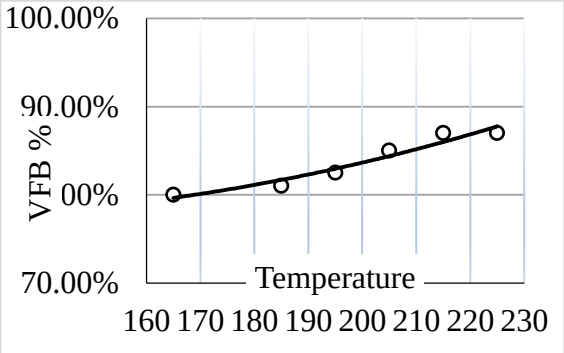

Fig.11:-*VFB vs. Overheating Temperature of Bitumen*

Optimum Binder Content

As the binder is overheated the OBC increases but taking consideration to the OBC of the original sample of the bitumen which is not overheated which is at 5.22%, the Marshall Stability, Flow Value and VTM decreases with the increase in temperature and VFB increases with the increasing temperature.

CONCLUSIONS

From the study the following conclusion could be done:

1. The penetration of the overheated bitumen decreases with increase in temperature and the softening point and viscosity of the overheated bitumen increases with the increase in temperature. This is obvious that when the bitumen is overheated it loses the volatile materials and oxide with oxygen to become.
2. The Penetration index of the bitumen is found to be less at 205^0C. So, the properties of the bitumen changes when heated at higher temperature and will become more brittle and the asphalt mix will be more prone to cracking.
3. The OBC of the asphalt mix with the overheated bitumen is found to increase with the temperature. Similarly, the air voids decreases and VFB increases as the bitumen becomes less viscous when heated at higher temperature and the aggregate minerals are coated thickly and more voids is filled.
4. The Stability of the mix decreases by about 30% than the original value with the increase in the temperature of overheated bitumen.
5. The unit weight of the mix increases due to thicker coating of the aggregate minerals and more voids are filled with increase in temperature of bitumen.
6. Taking the consideration of the OBC of the original mix, the Stability value of the mix is found to be decreased by 25% and the flow value decreased by about 5%. So, during the construction works the temperature of the bitumen should be carefully checked and

should not be overheated. The overheating of the bitumen will decrease the strength of the mix and make bitumen more brittle.

LIMITATIONS

1. Various types of bitumen tests should be done to determine the effect of overheated bitumen on its rheological properties. (Only penetration, softening and viscosity has been carried out.)
2. The effect of overheated bitumen on Marshall Properties of asphalt concrete has only been tested and properties other than Marshall need to be tested to determine the effect on various properties of asphalt concrete.

REFERENCES

1. Michal Sarnowski, Karol J. Kowalski, Jan B. Krol and Piotr Radziszewski, 2019, *Influence of Overheating phenomenon on Bitumen and Asphalt Mixture Properties.*Faculty of Civil Engineering, Warsaw University of Technology, 00-637 Warsaw, Poland.
2. Senja Rum Harnaeni, F. Pungky Pramesti, Arif Budiarto and Ary Setyawan, 2018. *The Effect of Temperature Changes on Mechanistic Performance of Hotmix Asphalt as Wearing Course with Different Gradation Types. AIP Conference Proceedings 1977, 030026.*
3. Marshall design and analysis, School of Engineering, Cochin University of Science and Technology, *Chapters, 4, 53p.*
4. Christine W. Curtis, Keith Ensley and Jon Epps, 1993. *Fundamental Properties of Asphalt-Aggregate Interactions including adhesion and absorption.* Strategic Highway Research Program, National Research Council, Washingon DC
5. E. Brown, J. McRae, and A. Crawley, 1989. *Effect of Aggregates on Performance of Bituminous Concrete.* In Implication of Aggregates in the Design, Construction, and Performance of Flexible Pavements, *ed. H. Schreuders and C. Marek (West Conshohocken, PA: ASTM International).*
6. Randolph C. Ahlrich, 1996, *Influence of aggregate gradation and particle shape/ texture on Permanent Deformation of Hot Mix asphalt pavement.* US Army Corps of Engineers, Technical Report GL-96-1
7. Kishan K. Vachhani, Prof. C.B. Mishra, 2014. *Assessing the impact of VG30 grade bitumen with and without additive (EVA) on short term aging. IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)* e-ISSN: 2278-1684, p-ISSN: 2320-334X.2014.11(6):36-40p.
8. Ivica Androjic, 2016.*Ageing of Hot mix asphalt.* University of Rijeka.
9. Stefan Vansteenkiste, Hilde Soenen and Gerhard Eberl, 2015. *Functional durability- related bitumen specification (FunDBitS), Corelations between bitumen and asphalt properties.* CEDR Transnational Road Research Programme Call 2013: Energy Efficiency- Materials and Technology.
10. Lorena Garcia Cucalon, Amit Bhasin, Emad Kassem, 2017. *Physicochemical characterization of Binder-Aggregate adhesion varying with temperature and moisture. Journal of Transportation Engineering, Part B: Pavements/* 2017.5(3)
11. Standard Specifications for Road and Bridge work 2073, *Government of Nepal, Ministry of Physical Infrastructure and Transport, Department of Roads*.