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Influence of Bentonite Additive on Bitumen and Asphalt Mixture Properties

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***Abstract*—**Asphalt surfaces are exposed to various weather conditions and dynamic loading caused by passing trucks and vehicles. In such situations, asphalt cement shows so different rheological-mechanical behavior. If asphalt cement isn't compatible enough, asphalt layer will be damaged immediately and expensive repairing procedures should be performed then. To overcome this problem, researchers study on mechanical improved asphalt cement. In this study, bentonite was used in order to modify bitumen characteristics and the modified bitumen's characteristics were investigated by asphalt cement tests. Then, the optimal bitumen content in various compounds was determined and asphalt samples with different contents of additives were prepared and tested. Results show using this kind of additive not only has caused improvement in bitumen mechanical properties, but also improvement in Marshall Parameters was achieved**.**

***Keywords*—**Asphalt mixture, Bentonite, Modified bitumen, Performance characteristics

I. Introduction

THE road network in each country plays a major role in connecting cities and regions and towards economical, social and cultural development. Hence, constructing new roads and performing maintenance and repair process is an important constructive project of country, while paving the roads is the major part of this construction. Asphalt layer has the protective role for road body and transfers compressive stresses from upper layers into lower ones. The quality of this layer is a factor which is effective on safety and comfort of road users and is considered in designing asphalt mixtures nowadays. Hence, constructing pavement with desirable quality and proper lifetime has been considered by designers. To reach this purpose, pavements researchers have been concentrated on increasing quality, stability and lifetime of pavements, reducing sonic pollution and preventing asphalt deterioration. Several researches have shown that filler has substantial effect on asphalt mixtures behavior. It fills the voids between aggregates and causes increase in, stability, density and load capacity of the mixture. In addition, it increases the extent of vulnerability and lowers the relative deformation. Furthermore, it raises the compressive and shearing resistance of asphalt through improving the bitumen cohesion.

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With all the stated advantages, using filler more than what is needed may lead to reduction in the porosity and increasing the stiffness of the mixture which is not desirable for mixture. According to this, the filler to bitumen ratio has been limited to 0.6 through 1.2 [1,2]. Filler should be prepared separately when not enough filler are produced after sieve analysis and should be added to materials in asphalt plant. In such circumstances, one can use limestone powder (the best of which is calcium carbonate), hydrated lime, cement or the powder of the other mineral stones [3].

Bentonite is a clay mineral formed fundamentally from the minerals of smectite group. Ionic substitution, ductility characteristic, ionic expansion and contraction are important properties of smectite family. In this research, bentonite is used to modify asphalt cement and the resulted bitumen is compare with non-modified AC60/70 bitumen. Finally asphalt mixtures were prepared using modified and non-modified bitumen and the marshall test were performed on them to compare bentonite modifier effect on asphalt mixtures.

II. Literature review

There have been various studies about modified bitumen. Yu J et al used montmorillonite and organic montmorillonite to modify bitumen. They studied the physical properties, dynamic and rheological behaviors and high temperature endurance of the stated bitumen. They showed that adding montmorillonite and organic modified montmorillonite causes increase in rutting resistance of mixture. In another study, Yu surveyed the effect of montmorillonite on oxidation temperature and bitumen aging properties [4].

AC 60-70 with different bentonite contents (0, 1, 2, 4 and 6) was studied and examined in other research. It was determined that bitumen modified by bentonite and organic modified bentonite (BT, OBT) has greater softening point value. Furthermore, by conducting the viscosity test it was revealed that viscosity of the resulting bitumen has been increased due to increment of the solid clay phase to the viscose phase of bitumen. By performing the ductility test it was determined that ductility of bitumen has been decreased by adding bentonite and organic modified bentonite since increasing ductile solid phase of clay to viscoselastic deformable phase of bitumen. Moreover, studying complex module (G*) changes versus temperature for BT and OBT modified bitumen showed that the complex module, which consisted of elastic and viscose modules, has been decreased with temperature increase. Phase angle (γ) changes vs. temperature for BT and OBT modified bitumen was tested as well. Phase angle is defined as difference between stress and tension in cyclic test. The greater γ shows the greater viscose behavior and smaller γ shows the greater elastic property. The results indicated increasing additives has led to phase angle increase.

From bending beam rheometer (BBR) at -12°C temperature, flexural stiffness for modified and non-modified bitumen after aging was computed via rotating thin film oven test (RTFO) and pressure aging vessel (PAV). The results showed adding bentonite and organic bentonite caused a decrease in stiffness in compare with the sample without additives as well as increase in low temperature cracks. The low value of flexural stiffness of aged modified bitumen relative to the specimens without additive indicates that clay planes in bitumen matrix prevent from molecules oxidation and light oils evaporation [5]. In another research, the effect of different values of bentonite mineral on bitumen properties containing 16% rubber powder was investigated. Bentonite with 1.5%, 3%, 4.5% and 6 % (bitumen weight percent) contents were used. The addition of bentonite to rubber containing bitumen caused to decrease in its penetration and softening point. The less the bitumen penetration, the more resistant the asphalt produced from it and the more bitumen softening point, the more efficiency of bitumen preserved in high temperatures. In addition, by increasing bentonite content, the thermal sensitivity value would be decreased and bitumen penetration index would be increased [6].

Another research by Toyota researchers on using nano-clay and silicate nano-particles as filler was conducted [7]. Silicate nano-particles polymer in comparison with net polymerized asphalt showed significant increase in mechanical and thermal properties [8,9].

III. Research Method

The research method includes the material selection, preparation of bitumen samples with different additive percentages and conducting the bitumen tests, preparing the asphalt samples with various percentages of additives and finally conducting Marshall Test on witness samples and samples containing additives in order to determine and compare Marshall Parameters.

A. Material selection and preliminary tests

In this study, crushed aggregate of Asb Charan mine of Roudehen (east zone of Tehran) were graded by number 4 gradation of Iranian asphalt pavement code and 5% filler were added to it. The gradation curve is illustrated in figure 1. Bitumen was AC60/70 of Pasargadae Oil Company which its physical properties are shown in table 1. Sodium containing bentonite was used as bitumen modifier, which the physical and geometrical properties of it are listed in tables 2 and 3 respectively.

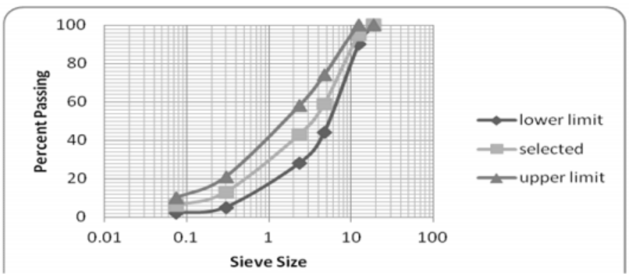

Fig. 1 mixture gradation curve

TABLE I
PHYSICAL PROPERTIES OF BITUMEN

Test	Standard	Result
Softening Point	ASTM D36	47°C
Penetration Degree (25°C)	ASTM D5	67 Deci-mm
Flash Point	ASTM D92	304°C
Ductility (25°C)	ASTM D113	> 100 mm
Density	ASTM D70	1.045 g/cm^3
Loss on Heating	ASTM D6	0.05 %
Solubility	ASTM D4	99.5%

TABLE II
PHYSICAL AND GEOMETRICAL PROPERTIES OF BENTONITE

Test	Standard	Measured Values
Special Gravity	ASTM C168	2.5 g/cm^3
Moisture Content	ASTM D2216	6% - 10%
Molecular Weight	**	100.1 gram
Boiling Point	**	1430 °C
Melting Point	**	400 °C
Crystal Type	**	Layer Crystalline
Color	**	Beige
Water Absorption	**	600%

** Based on Dorin Kashan Corporation's Information

TABLE III
BENTONITE GRAINING

Remained according to the mesh	Sieve No.100	Sieve No.200	Sieve No.325
Bentonite	2%	2.5%	20%

In this research, 10%, 15%, 20%, 25% and 30% were chosen as bentonite content. Bitumen and bentonite were blended at 140°C. Modified and non-modified bitumen properties were evaluated and to compare Marshall Parameters of mixtures prepared with bitumen, asphalt samples with mentioned additive content were prepared using witness samples optimum bitumen content was.

B. Preparing Samples in Laboratory

To determine the optimum bitumen content, eighteen samples of asphalt mixture with 4%, 4.5%, 5%, 5.5%, 6% and 6.5% of non-modified bitumen were prepared and after performing Marshall Tests, the optimum bitumen content was determined. In order to prepare bentonite modified specimens, aggregates were heated up to 170°C and modified bitumen containing various additive contents were heated up to 140°C, then three samples were prepared for each bentonite content. The mixtures were prepared using Marshall compaction method with 75 blows on each side .The specimens were placed in laboratory temperature for two hours to cool down according to Iranian Pavement Code. After that, specimens were brought out of molds and Marshall stability and flow and density tests were done on them which the results were compared with witness samples. The results can be seen in figures 2 to 12 [10].

The additives affected bitumen properties including penetration, softening point and ductility which affect asphalt mixture directly. In order to study the bitumen sensitivity to temperature changes and to determine relative stiffness of bitumen, the tests were performed on bitumen as well. Hence, bitumen samples blended with various bentonite additive contents of 10%, 15%, 20%, 25% and 30% of bitumen weight were prepared and penetration, softening point and ductility tests were carried on them and compared with witness samples, which results were shown in figures 13 through 15.

IV. Test Results

From the set of performed tests on bitumen (softening point, penetration and ductility) and Marshall Tests on mixtures, the following results were obtained:

A. Marshall Test results

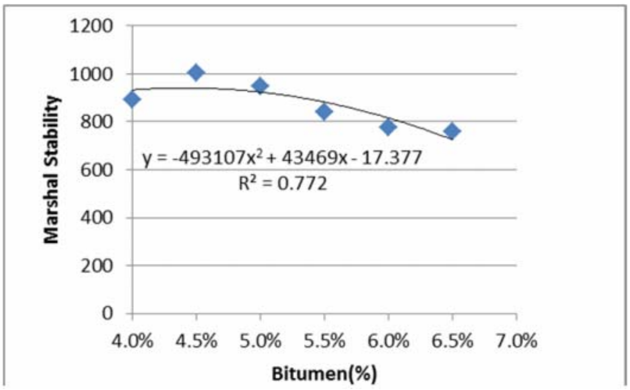

Fig. 2 Marshall Stability vs. changes of asphalt mixture

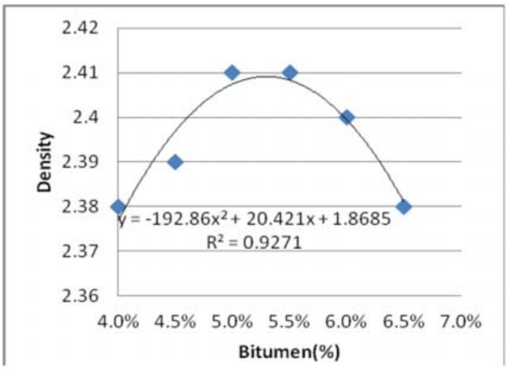

Fig. 3 Density vs. bitumen content

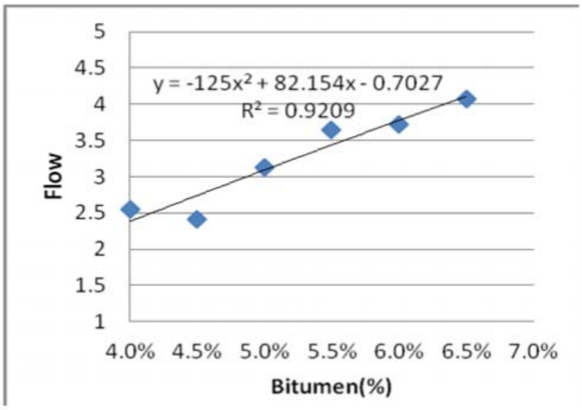

Fig. 4 Marshall flow vs. Bitumen Content

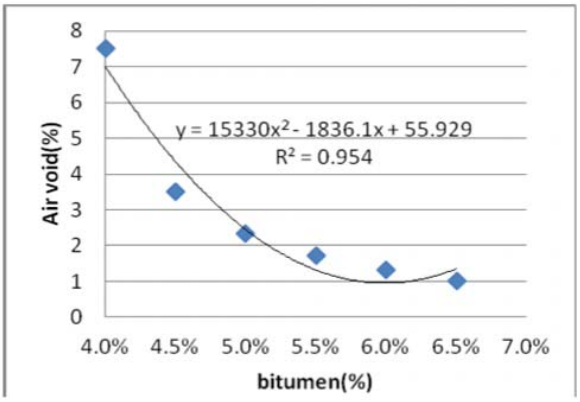

Fig. 5 Air voids vs. bitumen content

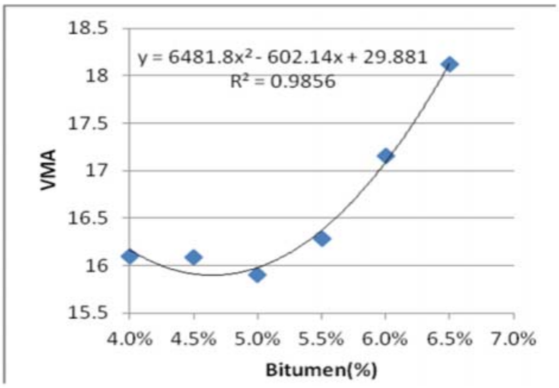

Fig. 6 Voids in mineral aggregates vs. bitumen content

TABLE IV
DETERMINING OPTIMUM BITUMEN CONTENT OF ASPHALT SAMPLES

Bitumen content			
Max. Marshall stability	Max. Density	Max. Air void	Optimum bitumen content
4.5%	5.5%	4.46%	4.9%

The result of marshall tests on bentonite modified specimens are illustrated in figures 7 to 12. According to these results, the value of optimum additive content was determined.

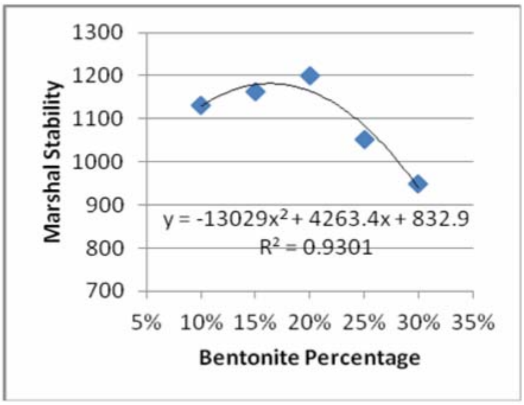

Fig. 7 Marshall stability vs. bentonite content

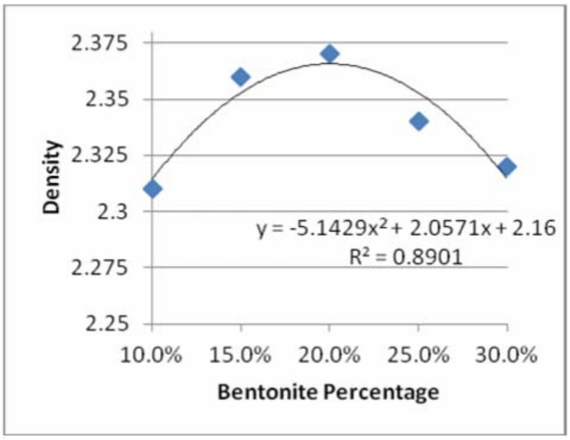

Fig. 8 Density vs. bentonite content

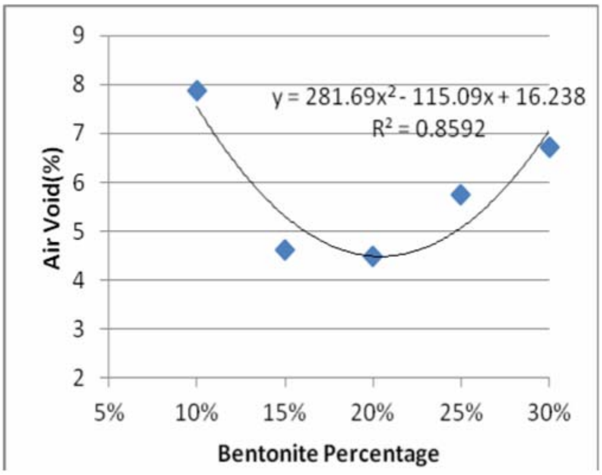

Fig. 9 Air voids vs. bentonite content

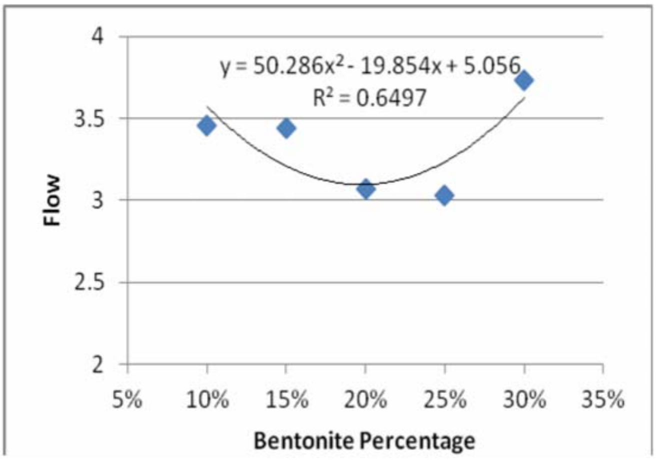

Fig. 10 Marshall flow vs. bentonite content

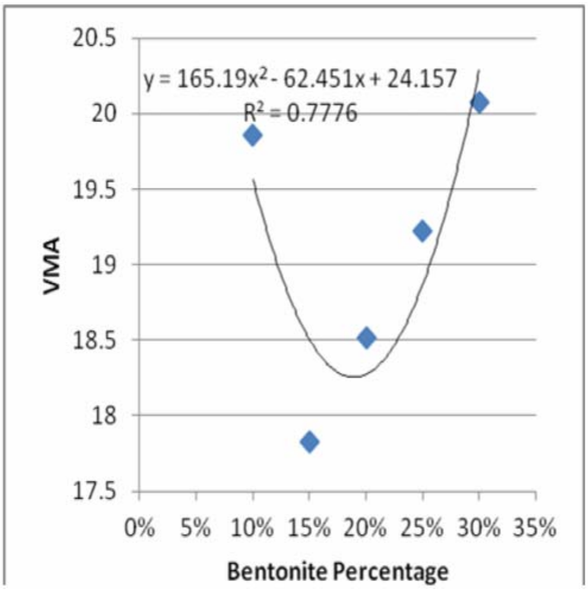

Fig. 11 Voids in mineral aggregates vs. bentonite content

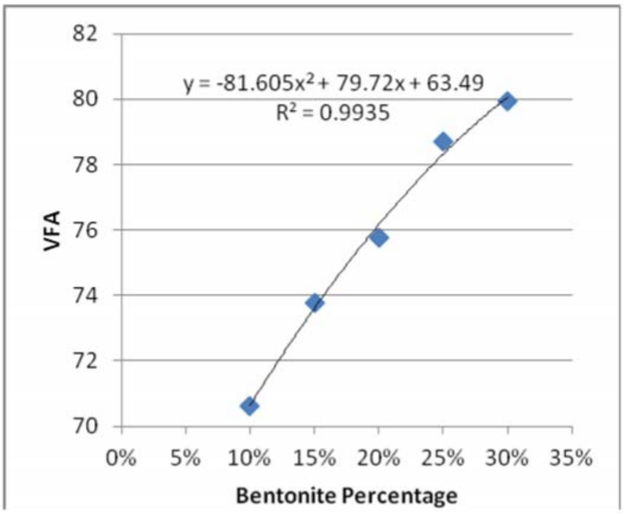

Fig. 12 Voids filled asphalt vs. bentonite content

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TABLE V
DETERMINATION OF OPTIMUM ADDITIVE CONTENT OF ASPHALT CONCRETE SAMPLES IN MIXING PLAN WITH MARSHALL METHOD

Bentonite content			
Max. Marshall stability	Max. Density	Max. Air void	Optimum Bentonite content
20%	20%	20%	20%

B. Bitumen Test Results

The result of Penetration, Softening point and Penetration Index test done on bentonite modified bitumen are shown in figures 13 to 15.

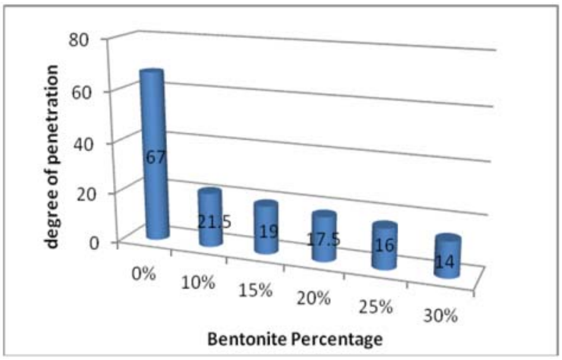

Fig. 13 Effect of bentonite on bitumen penetration

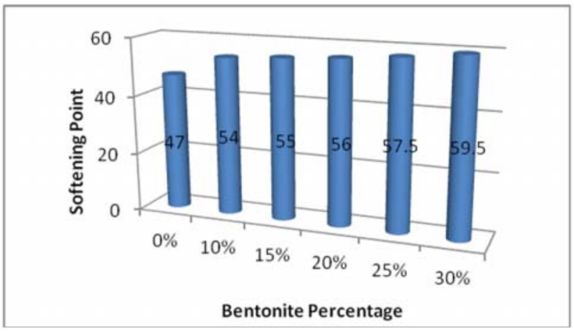

Fig. 14 Effect of bentonite on bitumen softening point

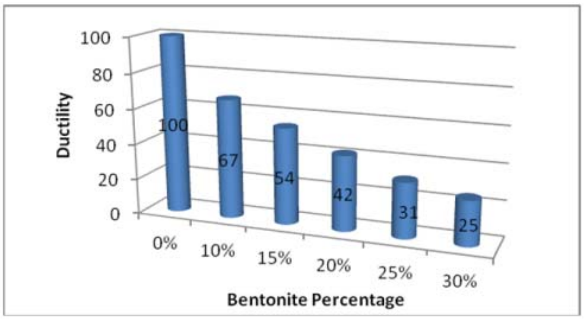

Fig. 15 Effect of bentonite on bitumen ductility

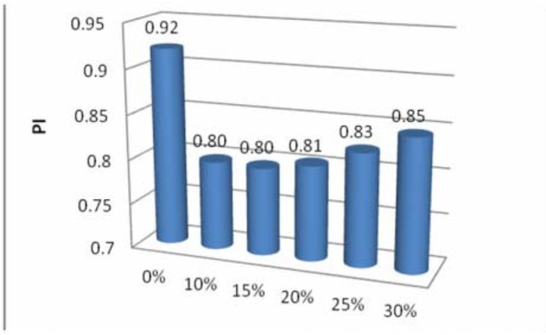

Fig. 16 Effect of bentonite on bitumen PI

V. DISCUSSION ON RESULTS

A. Bitumen tests results analysis

Regarding figures 13 to 15, it is obvious bentonite content increment, reduced penetration and ductility of bitumen. Bentonite content increase led to increase in softening point as it is obvious from figure 14. Clay fragile solid phase increase vs. viscoelastic phase of ductile bitumen which will result in bitumen ductility decrease. Moreover, one can find by considering figure 16 that the value of bitumen penetration index decreases with bentonite addition in comparison with non-modified bitumen. By the way, increasing bentonite content will lead to increase in PI. Bentonite has high content of silica (more than 70%) and a proper diffusion of it in bitumen phase results in bitumen stiffness. Consequently, the modified bitumen need time to change to liquid phase, so the penetration is low. The smaller the bitumen penetration, the more load capacity of produces asphalt mixture is and the more bitumen softening point, the more efficient the bitumen will be.

B. Marshall Tests results analysis

Considering Marshall Tests results of asphalt mixture containing bentonite and control asphalt mixture illustrated on figures 2-6, the trend of Marshall Parameters change is as follows:

According to figure 2, bentonite increases Marshall stability about 1.2 times of control mixture. The increase in the viscosity of bentonite modified bitumen, which leads to Marshall stability increase and improvement of mixture efficiency is the reason for it. The viscosity increase value of bitumen while using bentonite in it is about 3%. By raising bitumen content in asphalt mixtures, Marshall flow progress have incremental rate. Using bentonite increased the void in Mineral Aggregates percentage (VMA) partially. This means that the value of this parameter in control mixtures is 16-18 %, while the range of this parameter in asphalt mixture containing bentonite is 17.83% and 20%. In addition, bentonite usage leads to decrease in specific weight up to 2%. According to the results, the optimum bentonite content is determined as 20%.

VI. CONCLUSION

The aim of this study was to evaluate the effect of bentonite addition on bitumen properties and Marshall Parameters. So, asphalt samples containing additive and control samples were prepared and Marshall Tests were carried on them. In addition, to evaluate bitumen properties, penetration, softening point and ductility tests were carried on modified and non-modified bitumen. According to the results, adding bentonite to bitumen leads to decrease penetration and ductility, and increase softening point o. In addition, Marshall stability and flow improved in bentonite modified mixtures in compare with witness mixtures. While using 20% bentonite (weight percent of bitumen) improves the properties of asphalt mixture more in comparison with the other contents and this content is introduced as optimum bentonite content in this research.

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