COMPARISON OF THE VOLUMETRIC PROPERTIES AND STABILITIES OF FIELD AND LABORATORY COMPACTED ASPHALT CONCRETE

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ABSTRACT

The aim of this study is to investigate the effects of field compaction conditions on the volumetric and stability properties of asphalt concrete and compare those properties to that of the specimens prepared with different blow numbers of Marshall hammer and different gyration of gyratory compactor at laboratory. For this purpose, a binder layer was constructed at different temperatures and different compaction energy on plentmix base layer on a large area. The binder layer was divided into 12 sections including four different compaction and three different road roller passes numbers. Laboratory specimens were prepared applying 45-55-65 and 75 Marshall hammer blow to both sides of the samples, and also 70-90-110-130 gyrations by using the loose mixtures taking from the plant. The volumetric and Marshall stabilities of samples were determined and compared with each other. Based on the results, the effects of different temperatures and the number of road roller passes on volumetric properties and stabilities were determined. Different alternatives, which give the same compaction, were determined in terms of different passes and temperatures. The laboratory compaction conditions that represent any of the field compaction, were assessed in volumetric properties. It was also determined that even if the field and laboratory samples had the same air void content they had different stabilities.

Keywords : Compaction, Gyratory, Mixture design, Voids, Density

1. INTRODUCTION

Bituminous binders have a highly significant impact on the performance of hot mix asphalts (HMAs) even though making up approximately 5-7% of the asphalt content by weight [1]. Bitumen has also a considerable influence on the compactibility of mixtures besides the effects of its rheological properties on the pavement performance. Production of a mixture at the desired density is quite difficult unless the mixing and compaction temperatures are kept at a level suitable to the employed binder. The amount of used binder is also influential on the compactibility. At sub optimal binder proportions, the compactibility might be lower as the sliding of paved aggregates over each other is more difficult. At the optimum binder proportion, the asphalt film thickness on the surface of paved aggregates is increased and the compactibility is facilitated.

The aggregate properties used in HMAs are also influential on compactibility. As the friction resistance is higher in mixtures containing aggregates with multi-cornered and rough surfaces, higher levels of energy is needed during their compaction. The flexibility or rigidity of the surface being paved, as well as the pavement thickness, are the other factors affecting compactibility. Among these factors, the most important one is the temperature level and the energy of compaction. Although it is desired to compact the HMAs at the temperature compatible with the viscosity of the binder, environmental conditions like windy, cloudy or sunny weather and a thin foundation layer might also affect the cooling speed of the mixture. Furthermore, the temperature of the thin pavements falls much more rapidly than it does in the thick pavements. Attaining the compaction level described in the design is tough due to the heat losses occurring during the transportation stage and the time intervals in between overrunning cycles of the road roller. The weights of the rollers to be used in compaction process, in addition to their usage of vibration and the number of roller passes all directly influence the compatibility.

The most important volumetric property in HMAs is the air voids. HMAs are produced containing an appropriate amount of air voids in order to allow an additional compaction to cope with traffic loads. Hot mix asphalts possess a certain level of air voids at the time of initial pavement. As time passes, a consolidation ensues due to the traffic loads. This consolidation results from the reduction in air voids inside the mixture and the total volume of voids between the aggregates. These two mechanisms are distinct from each other and depend on the temperature-viscosity relationship of the asphalt [2]. The rising pressure of voids inside the diminished air voids forces the asphalt to move, hence inducing a lower film thickness over the asphalt and decreasing the distances between the aggregates. The bitumen acts as a grease between the aggregates by flowing into the air voids, thus the aggregates can displace freely as the friction resistance among them is largely removed. Consequently, any changes in the optimal level of air voids culminates in damages at any point during the life of the pavement [3].

In the studies conducted, it was determined that the specimens prepared by the gyratory compactor with an angle of 1.25^{o} exhibit the most similar properties with the specimens obtained from the field with respect to stiffness modulus, creep stiffness, bulk specific gravities and void content; while Marshall hammer and gyratory compactor methods yield different proportions of optimum binder content for the mixtures, especially in the case of crumb rubber entrained mixtures whose volumetric properties were affected much more severely from the temperature level than the compacting method [4, 5]. In the specimens prepared by gyratory compactor, the most convenient air void distribution was exhibited by the specimens with a diameter and height of 120 mm, while the distributions of the specimens prepared by roller compactor were largely similar to those in the field. On the other hand, it was recorded that for the purpose of obtaining a homogenous mixture in terms of air void distribution, it was needed to prepare large scale specimens and discard the outer parts to extract the specimen from the center section only [6]. In a study conducted by SHRP, it was determined that the most convenient compaction with respect to mixture stiffness was achieved by roller compactor as it also resembled the field conditions in the best manner [7]. In another study, it was recorded that aggregates in the mixtures prepared by Marshall hammer were fractured and the gradation deteriorated, which was attributed to the aggregates' abrasion resistance and flat and elongated structure [8].

In this study, the field and laboratory compaction conditions were assessed with evaluating different temperatures and compared in conjunction with the volumetric and stability properties of the hot mix asphalt. This study differ from the others by taking into account both compaction energy and compaction temperatures. Besides the field compaction represent the real application by using both pneumatic and tandem rollers on the layer series.

2. MATERIAL AND METHOD

In this study, the pavement layer was constructed by laying the binder layer over a base layer built on an area of 600 m^2 at various temperatures and compaction energies. In the binder layer, bitumen with a penetration degree of 81 and a limestone aggregate whose gradation and properties are listed in Table 1 were utilized. The binder layer was paved over the foundation layer with 12 different techniques in accordance with the field study plan illustrated in Figure 1.

Table 1: Physical properties of the aggregate

Sieve size (mm)	25.4	19.1	12.7	9.52	4.76	2.00	0.42	0.17	0.075
Passing (%)	100	88.2	70	59.8	44.6	29.1	12.6	7.9	5.6
Specific gravity (g/cm^3) (Coarse, fine, filler)			2.669 2.610 2.715						
Abrasion loss (%) (Los Angeles)			24						
Frost action (%) (with Na_2SO_4)			2.0						
Stripping resistance (%) (Nicholson)			70-75						

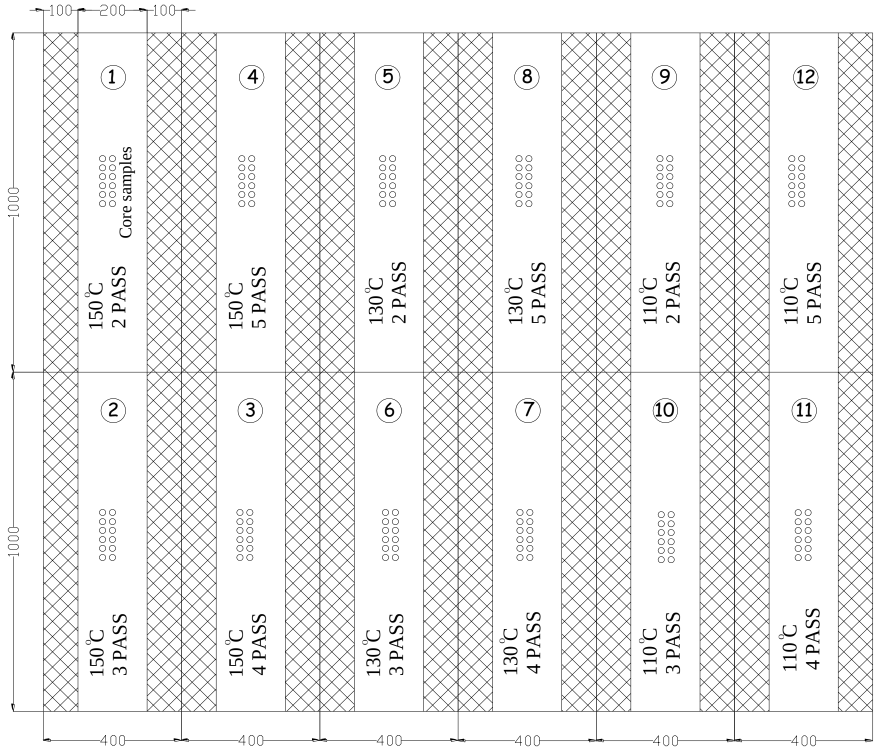

Figure 1: Field study plan

In the lying and compacting of binder layer, the effects of temperature and compaction energies were investigated in light of observations at temperature levels of 110°C, 130°C and 150°C and 2, 3, 4 and 5 passes by the roller. As for the compaction procedure, the pneumatic roller passed once over all the regions, followed by a vibrating tandem roller overrunning by various times depending on the regions, concluded by a single pass by the tandem roller over all regions without any vibration (Figure 2). A total of 16 core samples were taken from each region to determine the volumetric properties of the specimens, and then the specimens with the highest and lowest proportion of air voids were discarded.

Figure 2: The construction of binder layer

The mixture specimens were prepared with the Marshall hammer and gyratory compactor in the laboratory by using loose mixture obtained from asphalt plant during the field construction. The compaction temperatures in the laboratory were taken into account as it is in the field. 45, 55, 65 and 75 blow for Marshall hammer, 70, 90, 110 and 130 gyration for gyratory compactor was used in the laboratory. In this study besides the volumetric properties of the specimens, Marshall stability of the specimens were also determined

3. EXPERIMENTAL PROCEDURE

The core specimens' volumetric properties such as bulk specific gravities (Gmb), air voids (Va), voids in mineral aggregate (VMA) and voids filled with asphalt (VFA) are given in Table 2. As seen from the table, the specimens compacted at 150°C with 4 and 5 passes of roller fell within the specified limits [10] for the binder layer and the specimens compacted with 5 passes were found to satisfy the means of specified limits in the most ideal manner. Although the criteria regarding Va and VMA were met in all procedures except for this compaction procedure, VFA criteria could not be fulfilled. Nevertheless, the specimens compacted at 130 °C with 5 passes of roller yielded VFA values acceptable within the limits of specification criteria.

Table 2: Volumetric properties of core specimens

Temperature	Pass number	Gmb	Va	VMA	VFA
150	2	2.338	7.11	15.62	54.50
	3	2.352	6.53	15.09	56.76
	4	2.375	5.63	14.27	60.58
	5	2.394	4.87	13.58	64.21
130	2	2.318	7.89	16.33	51.69
	3	2.335	7.23	15.73	54.04
	4	2.350	6.62	15.17	56.42
	5	2.371	5.80	14.43	59.84
110	2	2.299	8.63	17.01	49.24
	3	2.311	8.18	16.59	50.74
	4	2.331	7.40	15.88	53.45
	5	2.349	6.67	15.23	56.18

In Figure 3, the variation in the air voids of the specimens depending on the number of roller passes and temperature level was given as the mean values for 12 specimens. The air void content decreased linearly at all temperatures as the number of roller passes increased. For instance, in case the number of roller passes rose from 2 to 5 at 150°C of temperature, the volume of air voids contracted by 31.5%, while the corresponding reductions were 26.4% at 130°C and 22.7% at 110°C, hence demonstrating the significant impact of roller passes on the air voids at high temperatures. As for 2 cycles of overrunning by the roller, the air voids decreased by 21.3% as the temperature dropped from 150°C to 110°C, whereas this same reduction was 37% in case of 5 roller cycles.

As a 36% variation in temperature varied the volume of air voids by 21% to 37% depending on the number of roller passes, a 36% change in the latter parameter induced a change between 8% and 13% in air voids depending on the level of temperature. Hence, it was inferred that temperature plays a more significant role than the compaction energy. In this regard, it is displayed in Figure 2 that same levels of air voids can be obtained under different conditions. It is shown that air voids similar to that obtained at 150°C and 2 roller passes can be generated by 3 roller passes at 130°C or by 4 passes at 110°C. Likewise, air voids similar to that obtained at 150°C and 3 roller passes can be generated by 4 roller passes at 130°C or by 5 passes at 110°C. As a rule of thumb, it was determined that the number of load passes should be increased by 1 in case the temperature dropped by 20 °C

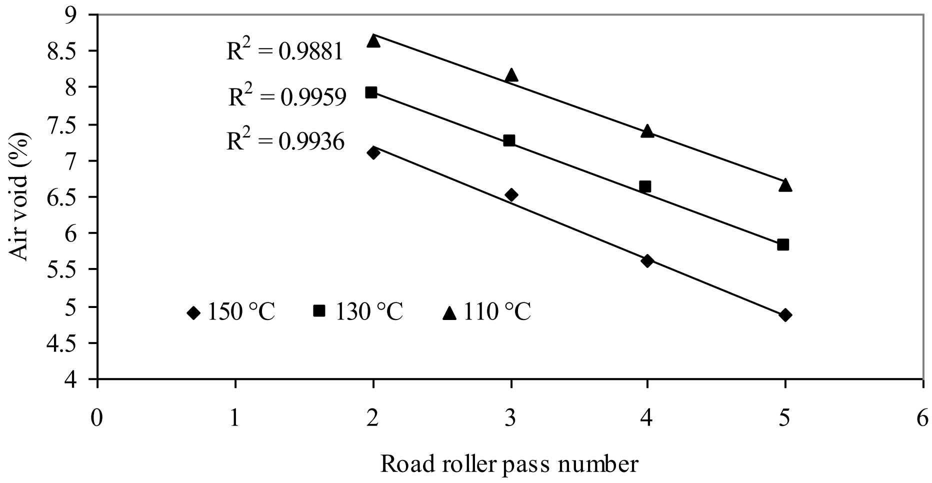

Figure 3: Variation on air voids of core specimens.

Variation in the proportion of voids filled with asphalt with the level of temperature and the number of roller passes is displayed in Figure 4. Here, it is seen that the curves converge at low compaction energies while diverging at higher levels of energy, hence displaying that temperature is more of a factor at higher compaction energies.

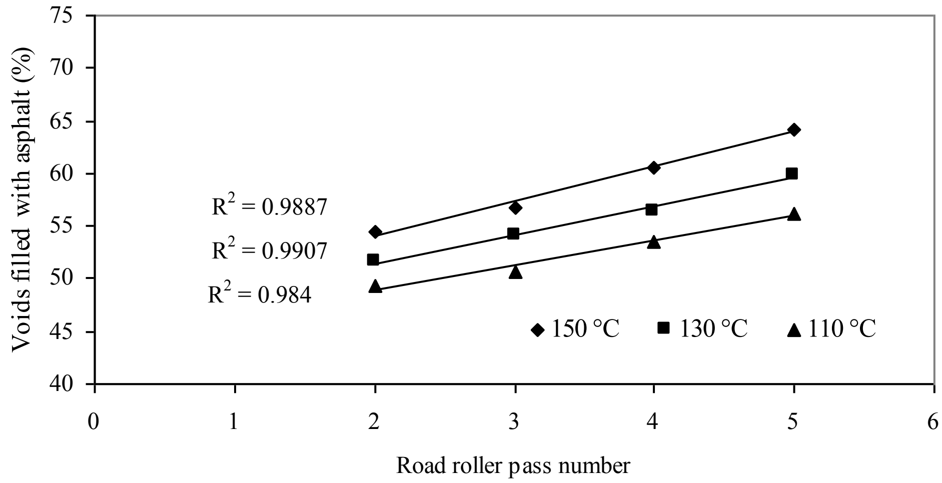

Figure 4: The variation on VFA of core specimens

The volumetric properties of specimens compacted with Marshall hammer are given in Table 3. The lower boundary for VFA was not met in any of the specimens while this particular value was most closely approximated by the specimens compacted at 150°C with 75 blows and yielded a void proportion of less than 6%. It is clearly implied that both of these parameters must be exceeded in order to achieve the volumetric properties at specified mean values. In Figure 5 and 6, variations in the air voids and the air voids filled with asphalt are given, respectively. As seen in these figures, the slopes of the curves belonging to specimens compacted at 150°C are higher than those of the others, which indicates that a rise in temperature is more influential on Va and VFA at high blow numbers.

Table 3: The volumetric properties of specimens compacted with Marshall hammer

Temperature	Blow number	Gmb	Va	VMA	VFA
150	45	2.318	7.89	16.33	51.69
	55	2.337	7.14	15.64	54.38
	65	2.350	6.64	15.20	56.28
	75	2.366	5.98	14.59	59.03
130	45	2.312	8.12	16.54	50.91
	55	2.325	7.61	16.07	52.67
	65	2.336	7.17	15.68	54.26
	75	2.354	6.47	15.04	56.97
110	45	2.304	8.45	16.84	49.81
	55	2.316	7.98	16.42	51.35
	65	2.326	7.58	16.05	52.76
	75	2.336	7.19	15.70	54.17

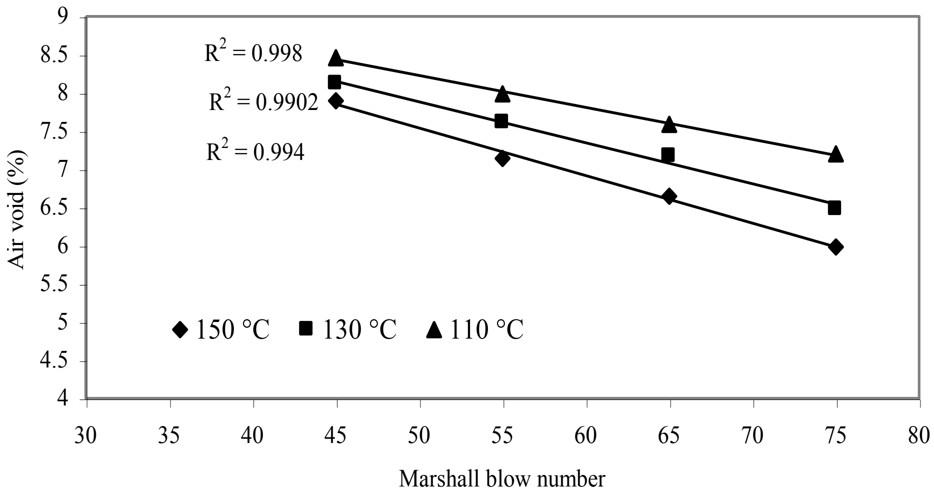

Figure 5: The variation on air voids of Marshall hammer compacted samples

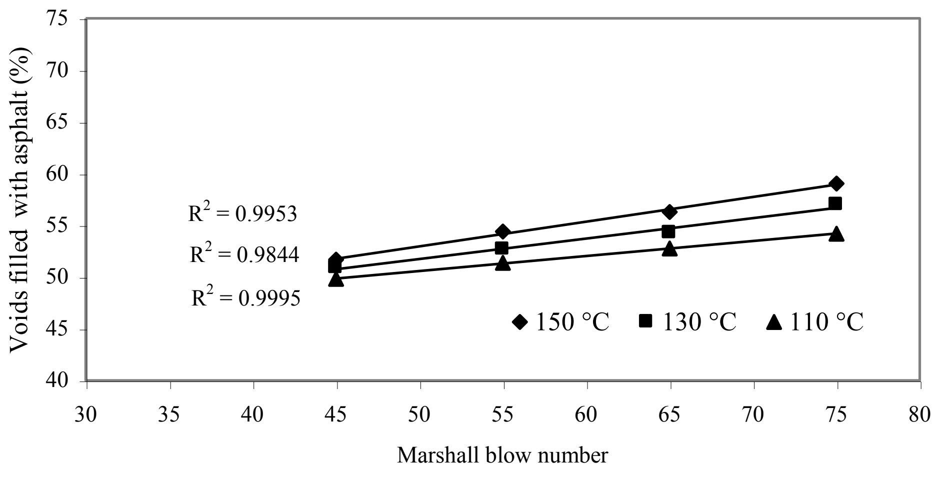

Figure 6: The variation on VFA of Marshall hammer compacted samples

The volumetric properties of specimens prepared with gyratory compactor are given in Table 4. As seen in the table, specifications limits for Va and VFA were not met by any of the specimens compacted at 110°C, whereas those prepared at 130°C with 130 cycles and at 150°C with either 130 or 110 cycles satisfied these limits. The variation in Va and VFA values of the specimens are given in Figures 7 and 8, respectively. As seen in the figures, the curves for temperature levels of 130°C and 150°C are mostly in parallel to each other while the 110°C curve diverge from these two to a certain extent, which in turn indicate that low temperatures are more negative conditions for gyratory compaction compared to both field and Marshall hammer compactions. An 85% increase in the number of gyrations in gyratory compaction reduced the void content by 23.6%, 22.3% and 17.6% at temperatures of 150°C, 130°C and 110°C, respectively.

Table 4: The volumetric properties of specimens prepared with gyratory compactor

Temperature	Gyration number	Gmb	Va	VMA	VFA
150	70	2.344	6.85	15.38	55.49
	90	2.360	6.21	14.81	58.05
	110	2.373	5.70	14.34	60.23
	130	2.385	5.23	13.91	62.41
130	70	2.337	7.14	15.65	54.38
	90	2.352	6.53	15.09	56.75
	110	2.366	6.01	14.62	58.96
	130	2.377	5.54	14.19	60.99
110	70	2.331	7.38	15.87	53.48
	90	2.341	7.00	15.52	54.90
	110	2.348	6.69	15.24	56.08
	130	2.364	6.08	14.68	58.60

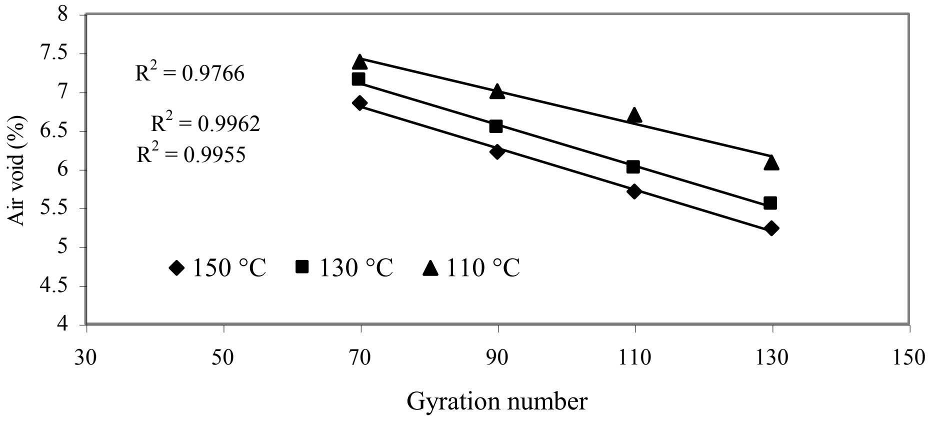

Figure 7: The variation on air voids of gyratory compacted samples

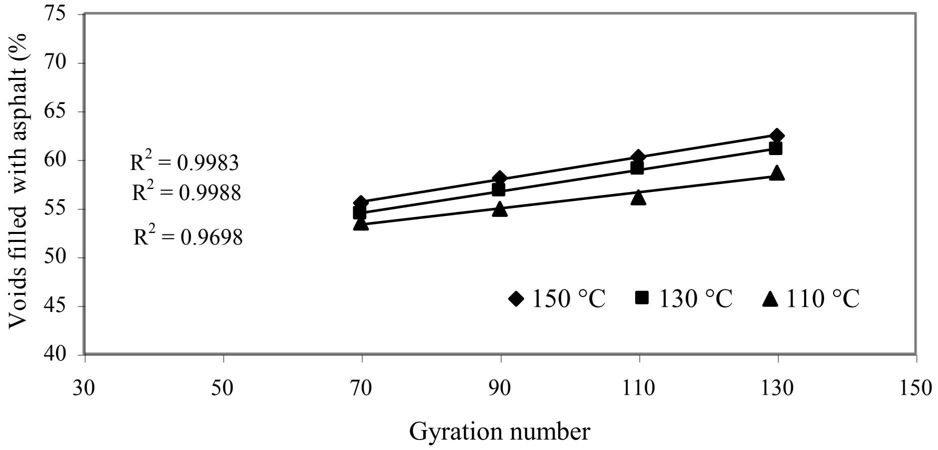

Figure 8: The variation on VFA of gyratory compacted samples

The relationship between the numbers of roller passes, the number of Marshall hammer blows and the number of gyrations with respect to the void contents is illustrated in Figures 9 and 10 for different levels of temperature. Here, a wider scale of values are taken into consideration with the assistance of the linear relationships between the void contents induced by 4 different numbers of roller passes, Marshall hammer blows and gyrations. It is with the assistance of these graphs that the number of required Marshall hammer blows or gyrations under laboratory conditions is determined in order to obtain the void contents generated by various numbers of roller passes in the field at various temperatures. Here, a linear relationship is observed between the field and laboratory compaction methods. Viewing the number of Marshall hammer blows or gyrations corresponding to field compaction at a certain number of roller passes at temperatures of 110°, 130°C and 150 °C, it is seen that the number of blows and gyrations increases with rising levels of temperature. In turn, this observation suggests that the impact of temperature on void content is more pronounced in field conditions compared to the laboratory compaction methods. However, the effect of temperature for both field and Marshall compaction methods both decrease at high compaction energies.

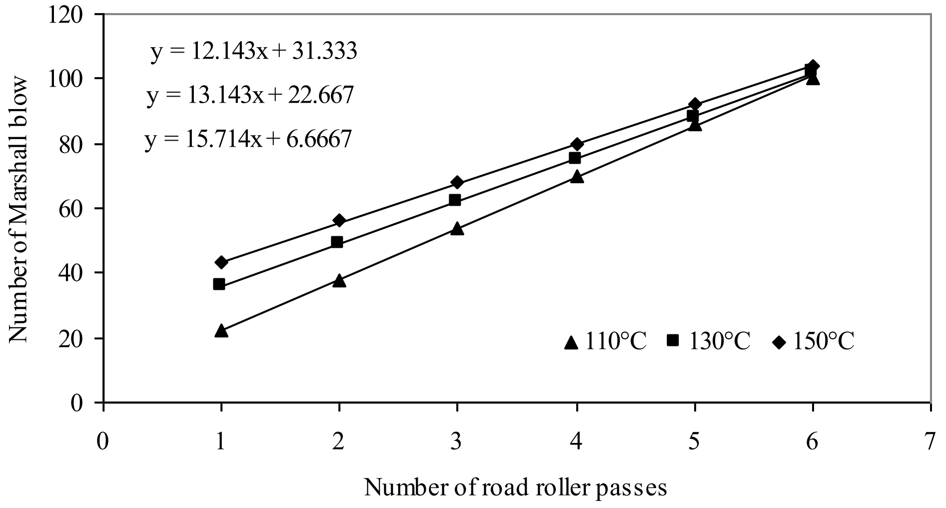

Figure 9: The relation between Marshall blows and roller passes

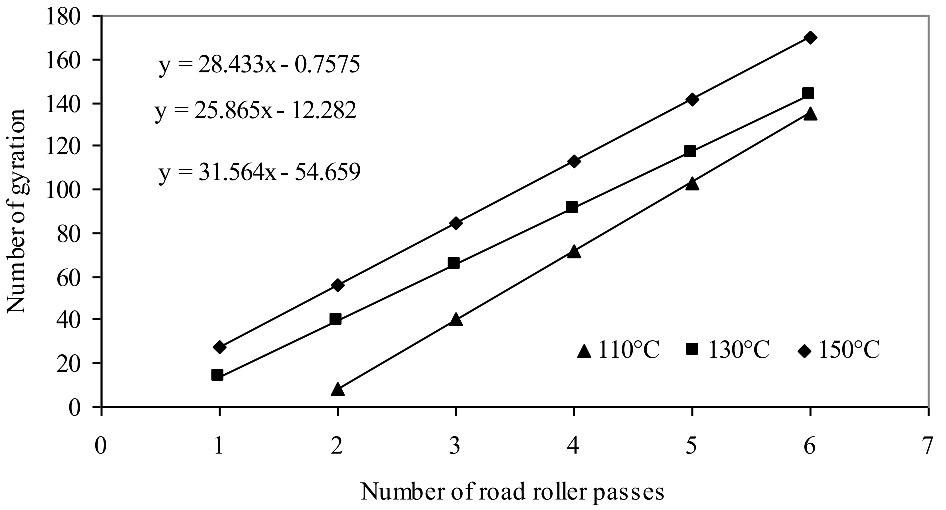

Figure 10: The relation between gyration numbers and roller passes

In Figure 11, the effects of compaction methods on the air voids of binder layer are collectively displayed. Here, the first term in the horizontal axis denotes the temperature while the second term denotes either of Marshall blow (B), gyration number (G) or road roller passes (P). From this graph, it is seen that any given content of voids induced by a particular number of roller passes at a particular temperature could also be obtained by various combinations in the laboratory.

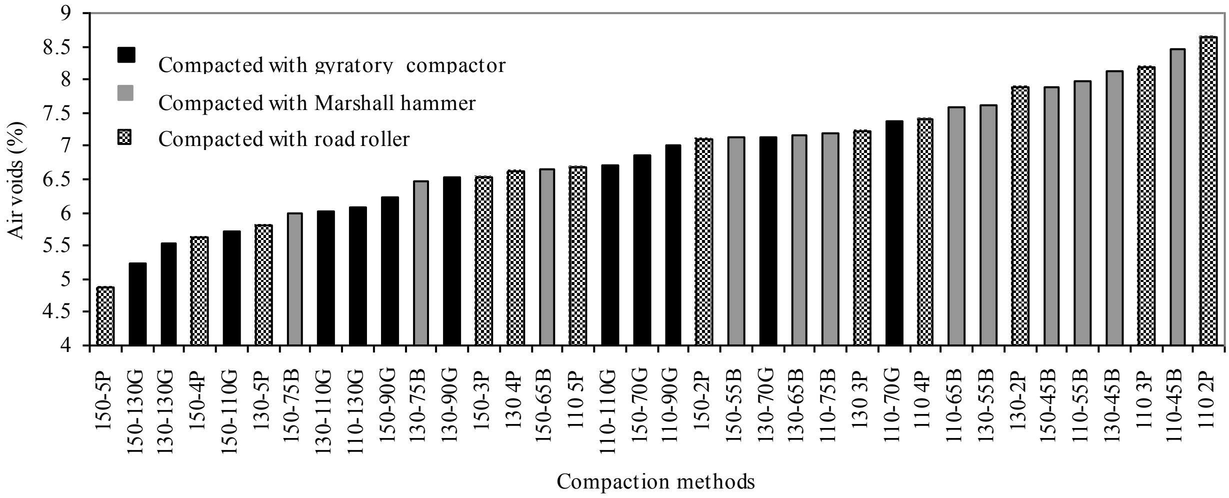

Figure 11: The relation between the air voids and compaction methods

In Figure 12, the effects of compaction methods on the stabilities of binder layer are collectively displayed. It is seen from the graph that the lowest 7 values are belong to field core specimens compacted at 110 °C and 130 °C. At these temperatures the specimens compacted with 45 Marshall blow give similar stability with the specimens compacted at 70 gyration. These stabilities can be obtained at 150°C 2 pass road roller and 130 °C 5 pass road roller in the field. 20 °C temperature drop required 3 adding road roller passes to satisfy same stability. At 110 °C the specimens compacted with 75 Marshall blow give similar stabilities with the specimens compacted at 110 gyration. As for the 130 °C the 65 blow and 130 gyration induced similar stabilities. The stabilities of core specimens compacted at 150 °C and 5 pass road roller can be achieved with very different combinations of laboratory conditions such as 150 °C 55 blow, 110 °C 130 gyration or 150 °C 70 gyration.

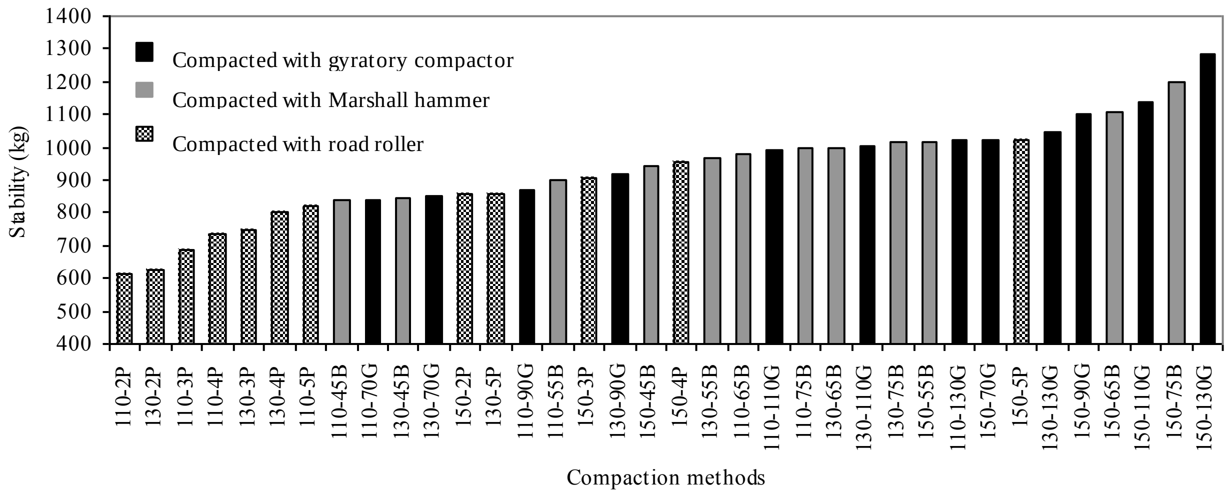

Figure 12: The relation between the stability and compaction methods

In Figure 13, the relationship between the air voids and stability of the specimens for different compaction methods are displayed. For all compaction methods, a linear relationship exists between the air voids contents and stability. It was also established that specimens with the same content of air voids might exhibit different stability values depending on their particular compaction method. In this regard, it is observed that gyratory compaction method most closely resembles field compaction compared to Marshall compaction. Although the specimens compacted with Marshall method exhibit higher stability values than those prepared with gyratory compaction in case the void content is greater than 6%, the situation is reversed at lower void contents.

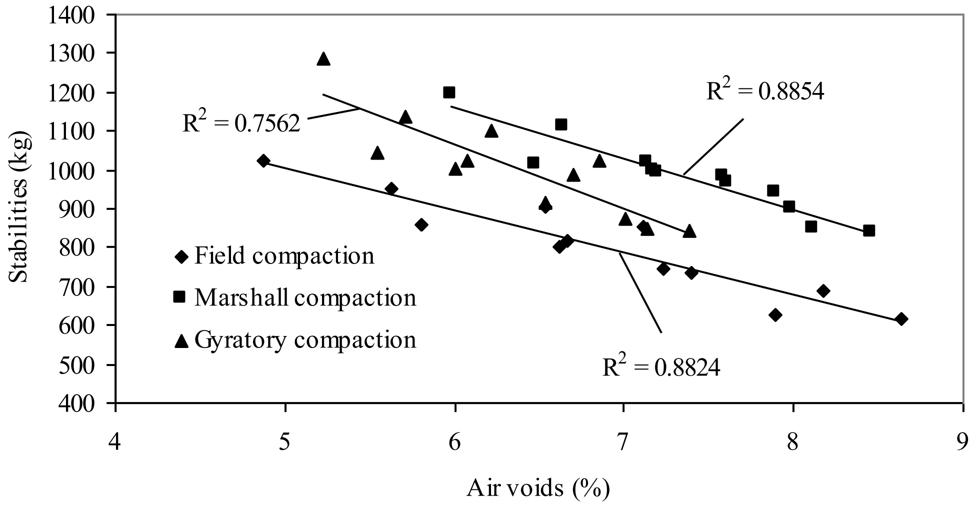

Figure 13: The relationship between the air voids and stability

4. CONCLUSIONS

Analyses conducted on specimens obtained from the field showed that the specimens prepared by 4 and 5 roller passes at 150°C satisfy the specified limits concerning the binder layer and that a linear relationship exists between the number of roller passes and the air voids. Moreover, it was also observed that the roller passes have a significant impact on the air voids at high temperatures in addition to that the temperature level play a more significant role compared to the compaction energy. It was inferred that the number of roller passes must increase by 1 if the field temperature were to fall by 20°C in order to keep the original air voids contents.

Under laboratory conditions, it was determined that temperature is hugely influential on the air void volume and content of air voids filled with asphalt in specimens compacted with Marshall hammer at high number of blows. Low temperatures led to more negative outcomes for gyratory compactor in comparison to field and Marshall hammer compaction. It was concluded that a linear relationship exists between the field and laboratory compaction methods with respect to air voids and stability, while the effect of temperature over the content of voids is much more prominent in the field compared to laboratory compaction methods; hence causing a mistake committed in the field concerning compaction temperatures to prove much more costly than a similar mistake concerning the laboratory compaction temperature. It is inferred that specimens with the same void content exhibit differing stability values depending on their respective compaction methods, which impact the specimens in different ways. It is also established that several properties must be taken into consideration to determine the specific laboratory conditions that would simulate a given set of field conditions.

In summary, this study allows the determination of which combinations in laboratory environment would yield the void contents and stability values obtained at any given level of temperature and number of roll passes in the field.

REFERENCES

1- Esnek kaplama malzemeleri el kitabı. Tunç, A., Asil Yayın Dağıtım, 352 s, 2004.

2- Asphalt aggregate mixture analysis system. Von Quintus H.L., Scherocman J.A., Hughes C.S., Kennedy T.W., NCHRP Report 338, Transportation Research Board, Washington, 1991.

3- Mechanics of air voids reduction of asphalt concrete using mixture theory. Krishnan J.M, Rao C.L., International Journal of Engineering Science 38, 1331-1354, 2000.

4- Comparative study of asphalt concrete laboratory compaction methods to simulate field compaction. Ziauddin A., Khan U, Hamad I. Al-Abdul Wahab, Asi I, Ramadhan R., Construction and Building Materials 12, 373-384, 1998.

5- The effects of compaction temperature on CRM mixtures made with the SGC and the Marshall compactor. Lee S.L., Serji N. A, Kwon S.Z., Construction and Building Materials 22, 1122–1128, 2008.

6- Influence of the compaction process on the air void homogeneity of asphalt mixtures samples. Dubois V., Chantal De La Roche, Burban O., Construction and Building Materials 24, 885–897, 2010.

7- Effect of the laboratory compaction method on permanent deformation characteristics of asphalt aggregate mixtures. Sousa J.B, Deacon J.A, Monismith C.L., Proc Assoc Asphalt Paving Technol,60, 533-585, 1991.

8- Application of digital image processing to quantitative study of asphalt concrete microstructure. Yue Z.W, Bekking W., Morin I., Transportation Research Record 1492, TRB, National Research Council, Washington, DC, 53–60, 1995.

9- Laboratory design and investigation of the properties of continuously graded asphaltic concrete containing recycled plastics aggregate replacement (Plastiphalt)., Zoorob, S.E., Suparma, L.B., Cement&Concrete Composites, 22, 233-242, 2000.

10- Highway technical specification. General Directorate of Highways of Turkey, Item No. 267., General Directorate of Highways of Turkey, Ankara, 2006.