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Influence of Different Methods on the Results of Unit Weight Tests for Asphalt Concrete: Part-III: Wax Sealing Method

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***Abstract*— Asphalt concrete plays an important role in pavement material for highway engineering applications. In addition, many kinds of sustainable materials are attempted in replacement of aggregates for waste reduction. In specification of measurement of unit weight of AC specimens the wax sealing method (WSM) using paraffin coating specimens, other than the direct measurement method (DMM) and the saturated-surface-dry weight method (SSDWM), is suggested for some special situations. However, there exist many influence factors that influence the precision of results using this method. This research is proposed to study difference between three experimental methods including DMM, SSDWM and WSM, and two kinds of specimens, the Marshall Specimens and drilled specimens. Furthermore, different contents and mixtures, e.g. natural aggregates and basic oxygen furnace (BOF) steel slag with coarse and dense grades, are tried and tested for investigating the difference. This paper conducts the Part III, i.e. wax sealing method (WSM).**

***Keywords*—Asphalt Concrete, Unit Weight, Basic-Oxygen-Furnace (BOF), Wax Sealing Method (WSM), Saturated-surface-dry weight Method (SSDWM).**

I. INTRODUCTION

It has been a long time the asphalt concrete (AC) pavements, acting as flexible pavements applied in highway engineering, become important and commonly adopted pavements in Taiwan. Special features of AC pavement for construction are relatively short working period, easy repair and construction [1, 2]. Furthermore, mechanical behaviour of AC pavements are: relatively low stiffness, high ductility, good flexibility, nice vibration absorbing capacity, high bearing capacity and stability, high fatigue resistance, good skid resistance, high workability, good impermeability, easy backfilling and swelling and cracking sustainability, etc.

In the practical application thickness and compaction of pavements are two representative indices for evaluation of the pavement quality.

Nowadays in Taiwan, according to the Chapter 02742 of Specification the thickness (e.g. CNS 8755) and compaction (e.g. CNS 12390) of the pavement are very important for the quality of construction but in reality only saturated-surface-dry weight method (SSDWM) other than wax sealing Method (WSM) was usually adopted in experiments [3]. Based on previous experience most of experts considered the unit weight obtained from WSM would be lower than those obtained from SSDWM. This leads to the WSMs were scarcely employed in practice.

Recently many research works are conducted on the application of recycling materials to pavement construction and repairs considering the waste reduction and environment protection. Among these the studies on the basic characteristics and engineering properties of basic oxygen furnace (BOF) steel slag used for replacement of natural aggregates for asphalt concretes [4-8].

Many techniques were also investigated and attempted for the measurement of thickness of pavement structures, such as impact echo method [9], ground penetration radar techniques [10-12] and non-destructive method [13].

In general wax sealing method is employed for the AC specimens with rate of water extraction greater than 2% or with obvious surface pores. However, in some situations WSM is not recommended for use because there may involve some uncertain effects, such as specific gravity of wax, the influence of adhesive wax on fluidization and stabilization during curing temperature, etc.

In all the research we employed the experimental approach by preparing Marshall Specimens and in-site drilling specimens, conducting three kinds of testing: (1) direct measurement method (DMM)[14]; (2) saturated-surface-dry weight method (SSDWM) [15]; and (3) wax sealing Method (WSM) [16] and finally we compare the results obtained from three different testing methods. This paper presents the process and results of Part III, i.e. wax sealing method (WSM) using paraffin coating specimens.

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II. Experiment Plan

A. Testing Materials

The testing materials employed in this study include the following:

(1) Asphalt: Oil-soluble asphalt is adopted;
(2) Natural aggregates: originating from rocks and stones;
(3) Artificial aggregates: coming from industrial by-products, such as blast-furnace (BF) slag and basic-oxygen-furnace (BOF) slag and electric-arc-furnace (EAF) slag.

In the research we adopted BOF slags as the ingredients of aggregates of AC samples, the mixture is 1:1 (BOF) using 6/8" and 3/8" slags simultaneously. The physical properties of the aggregates are shown in Table I.

The physical properties of asphalt used in preparing experimental samples such as specific gravity and viscosities measured at different temperatures are shown in Table II.

TABLE I
Physical Properties of BOF Slags Aggregates

Item	Property	Data
1	Specific Gravity	3.32
2	Los Angels Abrasion	10.3 %
3	Sand Equivalent	92.5 %
4	Liquid Limit (LL)	NP
5	Plasticity Index (PI)	NP
6	Potential Expansion	2.5 %
7	Unit Weight	2.58
8	pH Value	12.5
9	Water Absorption	3.5 %
10	Fractured Percentage	100 %
11	Flakiness Index	3.2 %
12	Soundness of Aggregates	5.6 % ~ 8.5 %

TABLE III
Physical Properties of Asphalt

Item	Property	Data
1	Specific Gravity	1.036~1.039
2	Viscosity: 60 °C Viscosity:135 °C	1970 (P) 3.9 (P)

B. Testing Variables

1) Submerged time: Based on the specification of CNS8757 in the WSM of the research the measurement of the bulk specific gravity and density depends on the difference of temperature of specimen and water.
2) Grade of mixtures: we considered coarse and dense grades of natural aggregates and basic oxygen furnace (BOF) steel slag.
3) Types of specimen: Marshall Specimen and drilled specimen.
4) Number of blows: considering three levels of equivalent single axle load (ESAL): heavy, medium and light, the corresponding number of blows is 75, 50 and 35, respectively.

C. Specimen Preparation

Totally 6 mixture combinations for Marshall Specimens were considered as follows:

(1) Natural material with 1/2 " dense grades;
(2) Natural material with 3/4 " dense grades;
(3) Natural material with 3/4 " coarse grades;
(4) BOF slag with 1/2 " dense grades;
(5) BOF slag with 3/4 " dense grades;
(6) BOF slag with 3/4 " coarse grades;

On the other hands totally 3 mixture combinations for drilled specimen were considered as follows:

(1) Natural material with 1/2 " dense grades;
(2) Natural material with 3/4 " dense grades;
(3) BOF slag with 1/2 " dense grades;

The grade distributions for each combination can be found in [17].

D. Mixture Preparation

The procedures for preparing the mixture materials can be referred to [17] and during the process of mixture temperature should be kept and the asphalt mixture should be quickly dumped into steel boxes as shown in Fig. 1 of [18].

E. Marshall Testing and drilled specimens Specimen Preparation

The specimen preparation for Marshall Testing are based on CNS 12395 specification and the detailed procedures can be followed as depicted in [19].

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The preparation of drilled specimen is according to the specification CNS8755 [14]. We need to take one drilled specimen per 1000 m^2 AC pavement (Fig. 1) and assure the perfect compaction of backfill. Furthermore, the offset of thickness of surface layer should be limited within 10% or 1 *cm*. If the thickness is not enough the surface layer should be excavated and backfilled at least with 5 cm thickness and 50 m length. The compaction also should be confirmed to reach 95% of experimental results of Marshall Specimen with the testing frequency of one drilled specimen per 1000 m^2 AC pavement

Figure 1 Typical drilled specimen obtained from AC pavement

F. Experimental Methods

The WSM can be summarized as follows:

(1) We first heated the wax be in fluid state with 25~30 minutes at temperature 100~120 ^oC;
(2) After the specimens exposed and dried in air at least 1 hour, then measured the weight of specimen in air, W_1;
(3) When the temperature of wax was lower to about 65 ^oC after 50~60 minutes, we started to seal the wax onto the specimens which were putting on the metal support;
(4) All the surface of each specimen should be sealed with wax completely so that water would not penetrate into the voids of specimen (Fig. 2); then put the specimen in air at least 30 minutes at temperature 25^{o}C±5 ^{o}C and measure the weight of specimen, W_2;
(5) Let the wax-sealed specimen be submerged wholly in water and measure the weight W_3;
(6) Evaluate the specific gravity of the wax, *G*.

The bulk specific gravity of WSM can be written as

$$SG = \frac{W_1}{W_2 - W_3 - (W_2 - W_1)/G_{wax}} \qquad (1)$$

Where W_1, W_2, W_3, G_{wax} are defined as

$$W_1 = weight\ of\ specimen\ in\ air,$$

$$W_2 = weight\ of\ wax - sealed\ dry\ specimen\ in\ air,$$

$$W_3 = weight\ of\ wax - sealed\ specimen\ in\ water\ within\ 25 \pm 1^o C$$

$$G_{wax} = specific\ gravity\ of\ wax\ at\ 25 \pm 1^o C$$

It should be noticed that in the experiments using WSM we should consider the following:

(1) The procedures should be according to the specifications CNS 8757 [16];
(2) The same specimen is first tested using SSDWM [20] and then tested using WSM;
(3) Specimen containing no water (absolutely dried).
(4) Selecting the quality of wax carefully because some wax might crack during cooling process (Fig.3).

Figure 2 Marshall Specimen after wax sealing

Figure 3 Crack of wax after drying

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III. EXPERIMENTAL RESULTS

A. *Natural material with 1/2" dense grades of Marshall Specimen*

Table III and Figure 4 show the results of measured thicknesses and unit weights, under 75, 50 and 35 blows, for natural material with 1/2" dense grades of Marshall Specimens using WSM. The thicknesses are nearly the same for different level of impact but unit weights vary proportional to the number of blows, the more the compaction the higher the unit weight results.

TABLE III
MEASURED THICKNESS OF NATURAL MATERIAL WITH 1/2 " DENSE GRADES OF MARSHALL SPECIMEN USING WSM

Level Of Impact	Measured Quantities	Thickness (cm)	Unit Weight (kg/m^3)
75 Blows	1	6.238	2355
	2	6.264	2344
	3	6.302	2336
	4	6.298	2334
	5	6.269	2348
	Averaged	6.2742	2343.4
50 Blows	1	6.331	2310
	2	6.329	2310
	3	6.278	2329
	4	6.315	2310
	5	6.308	2313
	Averaged	6.3122	2314.4
35 Blows	1	6.293	2278
	2	6.304	2276
	3	6.275	2280
	4	6.246	2289
	5	6.248	2293
	Averaged	6.2732	2283.2

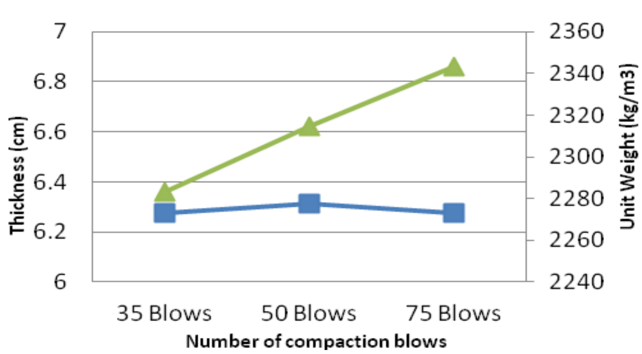

Figure 4 Averaged thickness and unit weight measurements for Natural material with 1/2" dense grades of Marshall Specimen using WSM under different impacts
(-■- Thickness; -▲- Unit Weight)

B. *Natural material with 3/4" dense grades of Marshall Specimen*

Table IV depicts the results of measured thicknesses and unit weights, under 75, 50 and 35 blows, for natural material with 3/4" dense grades of Marshall Specimens using WSM.

Figure 5 shows thickness and unit weight obtained for three levels of impact depend on level of impact. The higher level of impact the higher unit weight obtained as expected.

TABLE IV
MEASURED THICKNESS OF NATURAL MATERIAL WITH 3/4 " DENSE GRADES OF MARSHALL SPECIMEN USING WSM

Level Of Impact	Measured Quantities	Thickness (cm)	Unit Weight (kg/m^3)
75 Blows	1	6.325	2376
	2	6.329	2363
	3	6.281	2382
	4	6.314	2370
	5	6.304	2376
	Averaged	6.3106	2373.4
50 Blows	1	6.266	2368
	2	6.311	2360
	3	6.307	2350
	4	6.324	2352
	5	6.302	2360
	Averaged	6.302	2358
35 Blows	1	6.228	2327
	2	6.226	2318
	3	6.227	2320
	4	6.189	2340
	5	6.198	2328
	Averaged	6.2136	2326.6

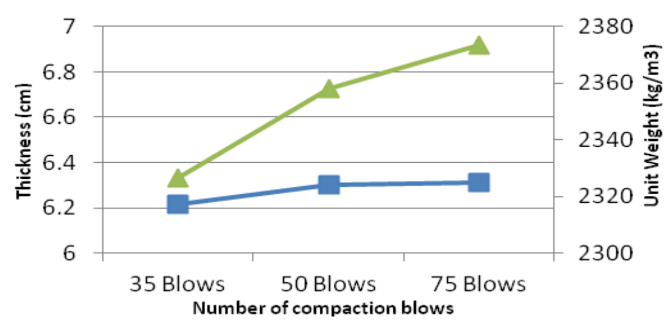

Figure 5 Averaged thickness and unit weight measurements for Natural material with 3/4" dense grades of Marshall Specimen using WSM under different impacts
(-■- Thickness; -▲- Unit Weight)

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C. Natural material with 3/4" coarse grades of Marshall Specimen

Table V and Figure 6 present the results of measured thicknesses and unit weights, under 75, 50 and 35 blows, for natural material with 3/4" coarse grades of Marshall Specimens using WSM. The thicknesses are nearly the same for different level of impact but unit weights vary proportional to the number of blows, the more the compaction the higher the unit weight results.

TABLE V
MEASURED THICKNESS OF NATURAL MATERIAL WITH 3/4 " COARSE GRADES OF MARSHALL SPECIMEN USING WSM

Level Of Impact	Measured Quantities	Thickness (cm)	Unit Weight (kg/m^3)
75 Blows	1	6.265	2337
	2	6.249	2343
	3	6.226	2346
	4	6.221	2352
	5	6.199	2356
	Averaged	6.232	2346.8
50 Blows	1	6.280	2319
	2	6.268	2324
	3	6.294	2312
	4	6.232	2333
	5	6.264	2322
	Averaged	6.2676	2322
35 Blows	1	6.242	2290
	2	6.192	2298
	3	6.221	2287
	4	6.238	2287
	5	6.269	2278
	Averaged	6.2324	2288

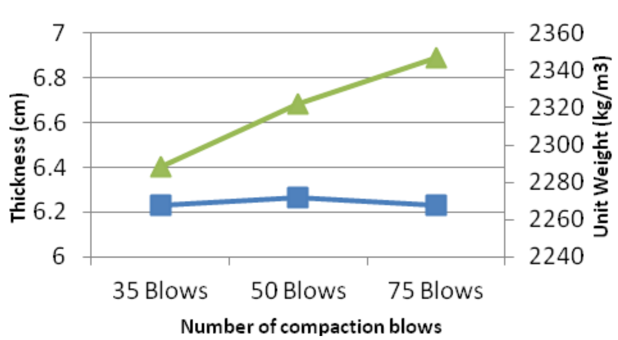

Figure 6 Averaged thickness and unit weight measurements for Natural material with 3/4" coarse grades of Marshall Specimen using WSM under different impacts
(-■- Thickness; -▲- Unit Weight)

D. BOF slag with 1/2" dense grades of Marshall Specimen

Table VI and Figure 7 reveal the results of measured thicknesses and unit weights, under 75, 50 and 35 blows, for BOF slags with 1/2" dense grades of Marshall Specimens using WSM. The thicknesses are nearly the same for different level of impact but unit weights vary proportional to the number of blows, the more the compaction the higher the unit weight results.

TABLE VI
MEASURED THICKNESS OF BOF SLAG WITH 1/2" DENSE GRADES OF MARSHALL SPECIMEN USING WSM

Level Of Impact	Measured Quantities	Thickness (cm)	Unit Weight (kg/m^3)
75 Blows	1	6.176	2636
	2	6.162	2640
	3	6.177	2629
	4	6.165	2636
	5	6.236	2603
	Averaged	6.1832	2628.8
50 Blows	1	6.297	2560
	2	6.221	2592
	3	6.266	2580
	4	6.252	2583
	5	6.226	2593
	Averaged	6.2524	2581.6
35 Blows	1	6.217	2551
	2	6.162	2577
	3	6.183	2569
	4	6.189	2563
	5	6.206	2559
	Averaged	6.1914	2563.8

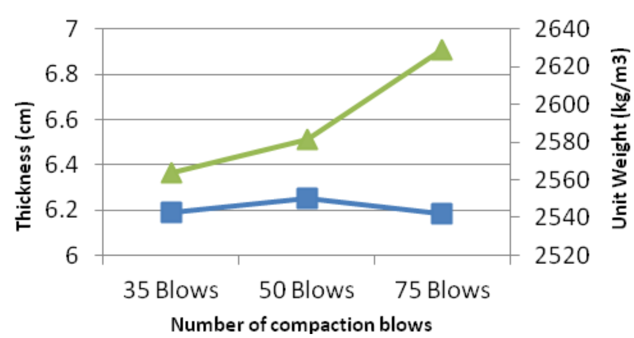

Figure 7 Averaged thickness and unit weight measurements for BOF Slag with 1/2" dense grades of Marshall Specimen using WSM under different impacts
(-■- Thickness; -▲- Unit Weight)

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International Journal of Emerging Technology and Advanced Engineering

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E. BOF slag with 3/4" dense grades of Marshall Specimen

It can be observed from Table VII and Figure 8 the results of measured thicknesses and unit weights, at different level of impact, for BOF slags with 3/4" dense grades of Marshall Specimens using WSM. Both thicknesses and unit weights are varying proportional to the number of blows.

TABLE VII
MEASURED THICKNESS OF BOF SLAG WITH 3/4" DENSE GRADES OF MARSHALL SPECIMEN USING WSM

Level Of Impact	Measured Quantities	Thickness (cm)	Unit Weight (kg/m^3)
75 Blows	1	6.362	2672
	2	6.347	2681
	3	6.374	2675
	4	6.381	2662
	5	6.384	2668
	Averaged	6.3696	2671.6
50 Blows	1	6.314	2625
	2	6.307	2627
	3	6.243	2648
	4	6.231	2652
	5	6.215	2658
	Averaged	6.262	2642
35 Blows	1	6.226	2591
	2	6.248	2578
	3	6.237	2583
	4	6.176	2613
	5	6.220	2587
	Averaged	6.2214	2590.4

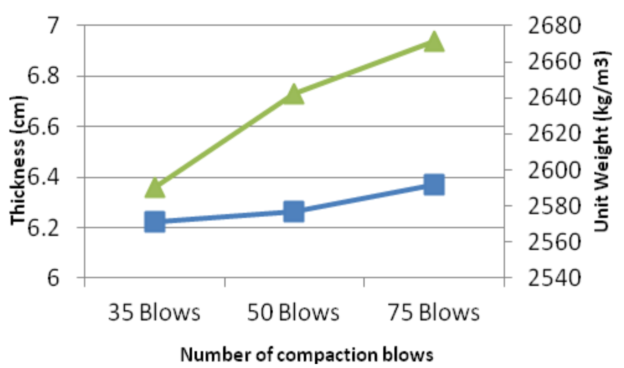

Figure 8 Averaged thickness and unit weight measurements for BOF Slag with 3/4" dense grades of Marshall Specimen using WSM under different impacts

(-■- Thickness; -▲- Unit Weight)

F. BOF slag with 3/4" coarse grades of Marshall Specimen

We can realize from Table VIII the results of measured thicknesses and unit weights, at different blows, for BOF slags with 3/4" coarse grades of Marshall Specimens using WSM. The averaged quantities of thickness and unit weight measurement under different number of impact can be observed in Figure 9. Different features occur for averaged thickness and unit weights related to number of blows.

TABLE VIII
MEASURED THICKNESS OF BOF SLAG WITH 3/4" COARSE GRADES OF MARSHALL SPECIMEN USING WSM

Level Of Impact	Measured Quantities	Thickness (cm)	Unit Weight (kg/m^3)
75 Blows	1	6.179	2672
	2	6.260	2645
	3	6.293	2628
	4	6.270	2639
	5	6.299	2636
	Averaged	6.2602	2644
50 Blows	1	6.306	2613
	2	6.359	2588
	3	6.333	2594
	4	6.334	2590
	5	6.237	2631
	Averaged	6.3138	2603.2
35 Blows	1	6.405	2571
	2	6.319	2586
	3	6.316	2580
	4	6.340	2577
	5	6.317	2584
	Averaged	6.3394	2579.6

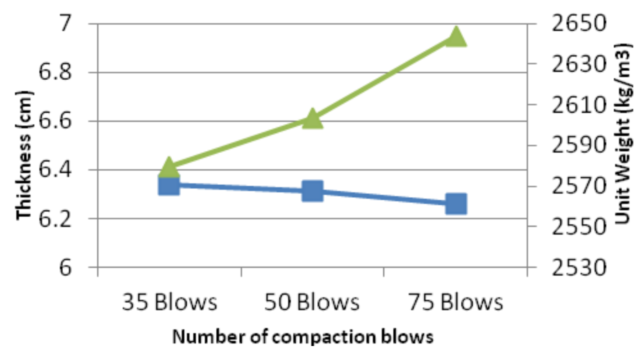

Figure 9 Averaged thickness and unit weight measurements for BOF Slag with 3/4" coarse grades of Marshall Specimen using WSM under different impacts

(-■- Thickness; -▲- Unit Weight)

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G. Natural material with 1/2", 3/4" dense grades and BOF slag with 1/2" dense grade of drilled Specimen

The major difference between Marshall Specimens and drilled specimens lies in the flatness of the top and bottom surfaces because drilled specimen are usually with cracks and holes after drilling. Figure 10 shows typical holes in the surface of a drilled sample from left side (Fig. 10(a)) and right side (Fig. 10(b)), respectively.

(a)

(b)

Figure 10 Typical holes in the surface of drilled specimen: (a) left side; (b) right side

We can identify from Table IX the averaged results of measured thicknesses and unit weights for natural material with 1/2", 3/4" dense grades and BOF slag with 1/2" dense grade of drilled specimen.

It can be shown that in Figure 11 the averaged unit weights of BOF slag with 1/2" dense grades depict the highest values of unit weight among these three specimens. This shows the benefit of using BOF steel slag in replacement of natural aggregates for AC pavement application.

TABLE IX
MEASURED THICKNESS OF NATURAL MATERIAL WITH 1/2", 3/4" GRADES AND BOF SLAG WITH 1/2" DENSE GRADES OF DRILLED SPECIMEN USING WSM

Types Of Specimen \ Measured Quantities		Thickness (cm)	Unit Weight (kg/m^3)
Natural material with 1/2" dense grade	1	4.894	2213
	2	5.720	2216
	3	4.999	2271
	4	6.746	2184
	5	4.687	2240
	Averaged	5.4092	2224.8
Natural material with 3/4" dense grade	1	4.998	2212
	2	4.804	2274
	3	5.076	2262
	4	5.128	2258
	5	4.981	2377
	Averaged	4.9974	2276.6
BOF slag with 1/2" dense grade	1	4.604	2734
	2	3.319	2755
	3	5.797	2830
	4	7.113	2621
	5	5.027	2875
	Averaged	5.172	2763

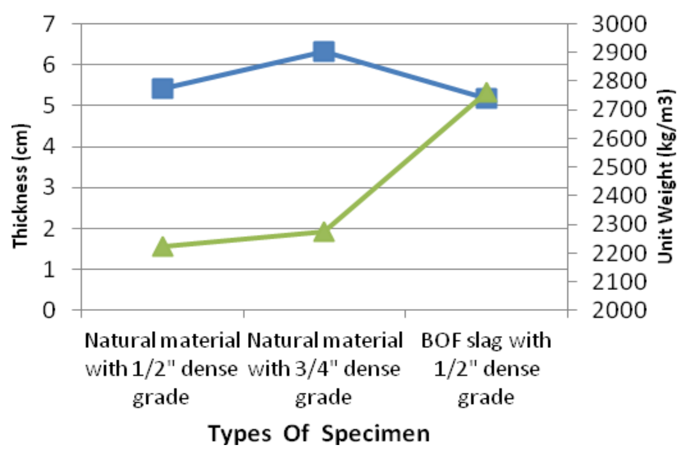

Figure 11 Averaged thickness and unit weight measurements for drilled specimens made of three different mixtures using WSM
(-■- Thickness; -▲- Unit Weight)

IV. CONCLUDING REMARKS

This paper presents one of the experimental methods for measurement of thickness and unit weight of specimen of asphalt concrete, i.e. the wax-sealing method (WSM) using paraffin coating specimens.. Some concluding remarks are summarized as follows:

1. When the WSM is employed for measurement of thicknesses and unit weights of AC specimens the quality of wax should be selected carefully because the wax might crack during cooling process.
2. As the number of impact increases, higher measured unit weights are obtained for all the Marshall Specimen with different mixtures using the WSM.
3. The averaged unit weights of BOF steel slag with 1/2" dense grade depict higher values than another two natural aggregates with 1/2"and 3/4" dense grades. This shows the benefit of using BOF steel slag in replacement of natural aggregates for AC pavement application.

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