International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 6, Issue 10, October 2016)

Influence of Different Methods on the Results of Unit Weight Tests for Asphalt Concrete: Part-I: Direct Measurement Method

Lin Ming-Chao[1], Kuo Fun-Min[2] , Huang Li-Jeng[3]

[1]Lecturer, [2]Master Student, [3]Associate Professor, Department of Civil Engineering, National Kaohsiung University of Applied Sciences, 80778, Taiwan, Republic of China

Abstract— **Asphalt concrete is usually employed for the pavement material in highway engineering and many kinds of sustainable materials are attempted for waste reduction and environmental protection. According to the Chapter 02742 of Specification the thickness and compaction 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. This research is proposed to adopt three experimental methods including direct measurement method (DMM), SSDWM and WSM, and two kinds of specimens:, the Marshall specimens and drilled specimens. Different contents and mixtures are tried and tested for investigating the difference. Experimental results show that DMM can only be used for measurement of Marshall specimen, submerge time has no obvious effect in SSDWM, the maximal difference of measured thickness and unit weight between WSM and SSDWM may reach 0.06cm and 0.85%, respectively. Finally overall grey correlation was employed and the results depict that volumetric specific weight and unit weight play the most important role among the content of specimen. This paper conducts the Part I, i.e. the direct measurement method.**

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

I. Introduction

Asphalt concrete (AC) pavements, acting as one of flexible pavements applied in highway engineering, become important and commonly adopted pavements nowadays in Taiwan due to its relatively short working period, easy repair and construction [1, 2]. The 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.

However, thickness and compaction of pavements are two representative indices for evaluation of the pavement quality.

Currently 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].

On the other hands, 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]. However, these approaches are relatively high costly.

In this research we employed the experimental approach. Preparing Marshall specimen and in-site drilling specimen, conducting three kinds of testing: (1) direct measurement method (DMM); (2) saturated-surface-dry weight method (SSDWM); and (3) wax sealing Method (WSM) and finally we compare the results obtained from three different testing methods. This paper present the Part I: direct measurement method (DMM).

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;

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 6, Issue 10, October 2016)

(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% and 3% stones 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	Abrasion and Impact of Los Angles Machine	10.3 %
3	Sand Equivalent	92.5 %
4	Liquid Limit (LL)	NP
5	Plastic Index (PI)	NP
6	Swelling Percentage	2.5 %
7	Unit Weight of Dry Soil	2.58
8	pH Value	12.5
9	Moisture Content	3.5 %
10	Fragile Percentage	100 %
11	Flatness Percentage	3.2 %
12	Sulphate Content	5.6 % ~ 8.5 %

TABLE II
PHYSICAL PROPERTIES OF ASPHALT

Item	Property	Data
1	Specific Gravity	1.036~1.039
2	Viscosity: 60 ^{o}C Viscosity:135 ^{o}C	1970 (P) 39 (P)

B. Testing Variables

Based on the specification of CNS8755 in the DMM of the research we adopted a way to measure the thickness of each sample at 4 different positions and take the averaged value [14]. Then we calculate the unit weight of the specimen. However, the effect of using 2- or 6-points thickness measurement on the Marshall and drilled samples remains to be studied.

C. Specimen Preparation

Totally 6 mixture combinations for Marshall specimen 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 combinations can be found in [15].

D. Mixture Preparation

The procedures for preparing the mixture materials can be referred to [15] 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.

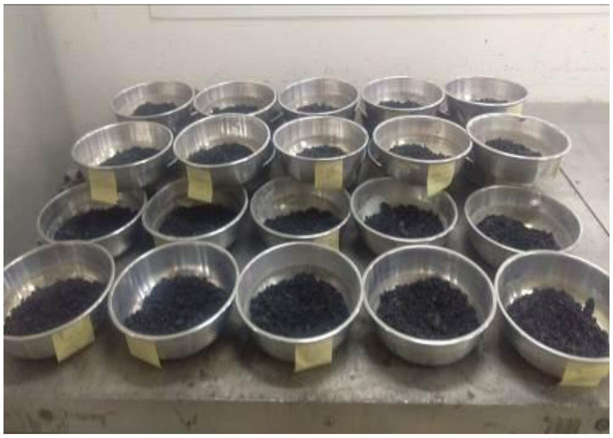

Figure 1 Prepared asphalt concrete mixtures

E. Marshall Testing Specimen Preparation

The specimen preparation for Marshall Testing are based on CNS 12395 specification and the detailed procedures can be followed as depicted in [16].

F. Experimental Methods

In the DMM, the thickness of specimen is measured by the callipers with selected number of points at both ends, e.g. typical 2-, 4- and 6- points and then the averaged thickness can be calculated as

IJETAE
EXPLORING RESEARCH AND INNOVATIONS

International Journal of Emerging Technology and Advanced Engineering

Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 6, Issue 10, October 2016)

(1) 2-points:

$$h = (h_1 + h_2)/2 \tag{1}$$

(2) 4-points:

$$h = (h_1 + h_2 + h_3 + h_4)/4 \tag{2}$$

(3) 6-points:

$$h = (h_1 + h_2 + h_3 + h_4 + h_5 + h_6)/6 \tag{3}$$

Among the above three methods only 4-points measurement is recommended by the specification. And 2- and 6-points are additional studied measurement and attempt for comparison.

After the thickness is obtained the unit weight of a cylinder of specimen can be calculated from

$$\gamma = \frac{W}{V} = \frac{W}{\pi D^2 h/4} \tag{4}$$

Equations (1)~(4) form the basic framework of DMM of this study.

When DMM is employed the following should be taken into consideration:

1) The two ends of specimen should be kept to be smoothly flat without any flaws or cracks and the callipers should be kept to be exactly vertical to the top surface when thickness is to be measured.
2) The circumference of top surfaces of specimen can be divided into 8 equal segments for 8 measurements to obtained averaged thickness.
3) If the specimens are absolutely flat on the top and bottom surfaces the measurement of thickness can be conducted by the use of suspension plate and the actual values of specimen can be obtained by the measured values minus the plate thickness. (Fig. 2).
4) When diameters are required top and bottom surfaces are measured 4 times, respectively, and then the averaged diameters are obtained. (Fig. 3).

Figure 2 Direct measurement on thickness of a Marshall sample

Figure 3 Direct measurement on diameter of a Marshall sample

III. EXPERIMENTAL RESULTS

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

Table III shows the results of measured thicknesses and calculated unit weights, using 2-, 4- and 6-points measurement respectively, for Natural material with 1/2" dense grades of Marshall Specimen. CNS 12395 specification is satisfied for these specimen (the specimen thickness should be kept within 63.5±1.27 mm).

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 6, Issue 10, October 2016)

Different impact levels results in different thickness; from 0.05cm～0.032cm difference in thickness for heavy class pavement (75 impacts), 0.006cm~0.010cm difference in thickness for intermediate class pavement (50 impacts), to 0.002cm~0.018cm for light class pavement (35 impacts). However, among these data nearly no difference of thickness exists between those obtained from 4- and 6-points; while a little difference measured by 2-points measurement. This might lead to a thumb rule that more than 2 points are required in the direct measurement of thickness of Marshall specimen.

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

Table IV depicts the results of measured thicknesses and calculated unit weights, using 2-, 4- and 6-points measurement respectively, for Natural material with 3/4" dense grades of Marshall Specimen. CNS 12395 specification is satisfied for these specimen. Different impact levels results in different thickness; from 0.012cm~0.035cm difference in thickness for heavy class pavement (75 impacts), 0.002cm~0.025cm difference in thickness for intermediate class pavement (50 impacts), to 0.003cm~0.029cm for light class pavement (35 impacts). However, among these data nearly no difference of thickness exists between those obtained from 4- and 6-points; while a little difference measured by 2-points measurement. From this results 4-points measurements as recommended by specification seems to be the best one.

TABLE III
MEASURED THICKNESS AND CALCULATED UNIT WEIGHT OF NATURAL MATERIAL WITH 1/2 " DENSE GRADES OF MARSHALL SPECIMEN

Types Of Specimen \ Measured Points		Measured Thickness (cm)			Calculated Unit Weight (kg/m^3)		
		2	4	6	2	4	6
75 Impacts	1	6.342	6.329	6.310	2318	2321	2330
	2	6.341	6.346	6.325	2314	2314	2321
	3	6.363	6.362	6.345	2314	2314	2320
	4	6.364	6.366	6.369	2308	2310	2307
	5	6.343	6.342	6.326	2320	2321	2326
50 Impacts	1	6.424	6.431	6.425	2278	2274	2278
	2	6.430	6.429	6.423	2273	2274	2275
	3	6.347	6.347	6.337	2305	2304	2309
	4	6.389	6.386	6.393	2284	2285	2282
	5	6.388	6.385	6.373	2288	2285	2293
35 Impacts	1	6.383	6.389	6.387	2244	2244	2242
	2	6.395	6.394	6.376	2242	2244	2249
	3	6.368	6.374	6.366	2246	2245	2247
	4	6.346	6.358	6.351	2252	2249	2251
	5	6.314	6.314	6.311	2271	2269	2272

TABLE IV
MEASURED THICKNESS AND CALCULATED UNIT WEIGHT OF NATURAL MATERIAL WITH 3/4 " DENSE GRADES OF MARSHALL SPECIMEN

Types Of Specimen \ Measured Points		Measured Thickness (cm)			Calculated Unit Weight (kg/m^3)		
		2	4	6	2	4	6
75 Impacts	1	6.404	6.404	6.389	2345	2347	2351
	2	6.432	6.436	6.464	2327	2324	2316
	3	6.358	6.352	6.335	2353	2355	2361
	4	6.376	6.388	6.411	2347	2342	2334
	5	6.386	6.396	6.384	2346	2342	2347
50 Impacts	1	6.356	6.353	6.354	2335	2336	2336
	2	6.444	6.446	6.444	2312	2310	2312
	3	6.369	6.367	6.359	2325	2328	2329
	4	6.367	6.370	6.392	2337	2335	2328
	5	6.375	6.376	6.366	2331	2332	2335
35 Impacts	1	6.346	6.340	6.327	2283	2286	2290
	2	6.362	6.358	6.371	2271	2270	2268
	3	6.385	6.364	6.393	2262	2270	2259
	4	6.326	6.336	6.350	2290	2286	2281
	5	6.299	6.300	6.297	2292	2291	2292

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

Table V presents the results of measured thicknesses and calculated unit weights, using 2-, 4- and 6-points measurement respectively, for Natural material with 3/4" coarse grades of Marshall Specimen. Different impact levels results in different calculated unit weights; from 7 kg/m^3~13 kg/m^3 difference in thickness for heavy class pavement (75 impacts), 0 kg/m^3~12 kg/m^3 difference in thickness for intermediate class pavement (50 impacts), to 1 kg/m^3~7 kg/m^3 for light class pavement (35 impacts).The errors of 2-, 4-, and 6- points measurements on thicknesses are all within 1%.

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

Table VI reveals the results of measured thicknesses and calculated unit weights, using 2-, 4- and 6-points measurement respectively, for BOF slags with 3/4" coarse grades of Marshall Specimen. Different impact levels results in different measured thickness are all within 0.024 for three levels of impacts.

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 6, Issue 10, October 2016)

TABLE V
MEASURED THICKNESS AND CALCULATED UNIT WEIGHT OF NATURAL MATERIAL WITH 3/4 " COARSE GRADES OF MARSHALL SPECIMEN

Types Of Specimen	Measured Points	Measured Thickness (cm) 2	4	6	Calculated Unit Weight (kg/m^3) 2	4	6
75 Impacts	1	6.385	6.367	6.367	2292	2299	2299
	2	6.356	6.347	6.378	2303	2307	2295
	3	6.322	6.347	6.355	2310	2301	2298
	4	6.326	6.329	6.325	2313	2312	2314
	5	6.306	6.305	6.301	2315	2316	2317
50 Impacts	1	6.371	6.383	6.375	2284	2282	2282
	2	6.368	6.400	6.402	2289	2276	2277
	3	6.438	6.434	6.426	2260	2262	2264
	4	6.339	6.340	6.341	2292	2293	2291
	5	6.394	6.394	6.394	2274	2274	2274
35 Impacts	1	6.343	6.356	6.356	2252	2249	2247
	2	6.304	6.321	6.323	2256	2251	2249
	3	6.375	6.381	6.384	2234	2230	2231
	4	6.341	6.345	6.344	2250	2249	2249
	5	6.425	6.414	6.413	2223	2227	2227

TABLE VI
MEASURED THICKNESS AND CALCULATED UNIT WEIGHT OF BOF SLAG WITH 1/2 " DENSE GRADES OF MARSHALL SPECIMEN

Types Of Specimen	Measured Points	Measured Thickness (cm) 2	4	6	Calculated Unit Weight (kg/m^3) 2	4	6
75 Impacts	1	6.221	6.235	6.237	2617	2611	2610
	2	6.236	6.245	6.244	2609	2605	2606
	3	6.233	6.251	6.257	2605	2598	2595
	4	6.257	6.256	6.259	2599	2598	2598
	5	6.284	6.276	6.274	2584	2587	2588
50 Impacts	1	6.363	6.379	6.385	2537	2527	2528
	2	6.295	6.306	6.313	2563	2557	2556
	3	6.354	6.330	6.343	2542	2554	2547
	4	6.319	6.333	6.320	2554	2550	2554
	5	6.305	6.315	6.315	2562	2556	2558
35 Impacts	1	6.284	6.285	6.288	2524	2523	2522
	2	6.245	6.243	6.236	2542	2544	2545
	3	6.263	6.272	6.273	2537	2532	2533
	4	6.244	6.245	6.246	2540	2540	2539
	5	6.293	6.290	6.287	2522	2525	2524

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

It can be observed from Table VII the results of measured thicknesses and calculated unit weights, using 2-, 4- and 6-points measurement respectively, for BOF slags with 3/4" dense grades of Marshall Specimen. There exists nearly no difference in the thickness measurement and unit weight calculation in these cases.

TABLE VII
MEASURED THICKNESS AND CALCULATED UNIT WEIGHT OF BOF SLAG WITH 3/4" DENSE GRADES OF MARSHALL SPECIMEN

Types Of Specimen	Measured Points	Measured Thickness (cm) 2	4	6	Calculated Unit Weight (kg/m^3) 2	4	6
75 Impacts	1	6.428	6.441	6.439	2645	2639	2640
	2	6.450	6.412	6.403	2639	2653	2658
	3	6.442	6.426	6.419	2646	2654	2656
	4	6.432	6.461	6.464	2643	2629	2630
	5	6.470	6.462	6.459	2632	2635	2637
50 Impacts	1	6.380	6.371	6.376	2599	2601	2600
	2	6.348	6.366	6.372	2610	2603	2600
	3	6.343	6.362	6.363	2606	2599	2598
	4	6.303	6.312	6.313	2621	2618	2617
	5	6.267	6.276	6.269	2635	2632	2635
35 Impacts	1	6.291	6.298	6.296	2563	2561	2560
	2	6.299	6.290	6.290	2558	2561	2562
	3	6.276	6.227	6.207	2563	2587	2592
	4	6.245	6.257	6.262	2585	2579	2578
	5	6.298	6.308	6.313	2557	2551	2551

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

We can realize from Table VIII the results of measured thicknesses and calculated unit weights, using 2-, 4- and 6-points measurement respectively, for BOF slags with 3/4" coarse grades of Marshall Specimen. The differences in measured thicknesses and calculated unit weights are also coming from 2-points measurements. In practical application of using DMM 2-points measurements are not recommended for Marshall specimen even in CNS specification.

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

The major difference between Marshall specimen and drilled specimen lies in the flatness of the top and bottom surfaces because drilled specimen are usually with cracks and holes after drilling.

Figure 4 shows the bottom surface of a typical drilled sample. From the results we can find that measurement correctness depends on the flatness of the top and bottom surfaces using the DMM in drilled specimen.

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 6, Issue 10, October 2016)

TABLE VIII
MEASURED THICKNESS AND CALCULATED UNIT WEIGHT OF BOF SLAG WITH 3/4" COARSE GRADES OF MARSHALL SPECIMEN

Types Of Specimen \ Measured Points		Measured Thickness (cm) 2	4	6	Calculated Unit Weight (kg/m^3) 2	4	6
75 Impacts	1	6.293	6.297	6.300	2625	2622	2622
	2	6.362	6.338	6.336	2603	2613	2614
	3	6.342	6.335	6.339	2608	2611	2609
	4	6.345	6.346	6.337	2607	2608	2610
	5	6.383	6.366	6.364	2600	2608	2608
50 Impacts	1	6.344	6.355	6.356	2595	2593	2590
	2	6.388	6.399	6.404	2574	2571	2567
	3	6.418	6.412	6.410	2561	2562	2565
	4	6.373	6.396	6.400	2575	2565	2564
	5	6.299	6.299	6.300	2605	2605	2604
35 Impacts	1	6.450	6.462	6.465	2550	2549	2545
	2	6.379	6.380	6.379	2561	2561	2561
	3	6.362	6.372	6.371	2561	2558	2557
	4	6.384	6.388	6.390	2559	2557	2557
	5	6.377	6.375	6.367	2561	2561	2565

Figure 4 The bottom surface of a typical drilled sample

We can identify from Table IX and Table X, respectively, the results of measured thicknesses and calculated unit weights, using 2-, 4- and 6-points measurement for Natural material with 1/2", 3/4" dense grades and BOF slag with 1/2", 3/4" dense grades of drilled Specimen considering the specimen non-cutting and cutting to be flat surfaces.

However, even after cutting the surfaces to be flat if there exist holes the measured results might be imprecise.

TABLE IX
MEASURED THICKNESS AND CALCULATED UNIT WEIGHT OF NATURAL MATERIAL WITH 1/2", 3/4" GRADES AND BOF SLAG WITH 3/4" DENSE GRADES OF DRILLED SPECIMEN BEFORE CUTTING SURFACES

Types Of Specimen \ Measured Points		Measured Thickness (cm) 2	4	6	Calculated Unit Weight (kg/m^3) 2	4	6
Natural material with 1/2" dense grades	1	5.317	5.435	5.547	2038	1993	1953
	2	6.163	6.101	6.083	2053	2078	2080
	3	5.657	5.805	5.867	2007	1956	1935
	4	7.242	7.111	7.157	2035	2072	2060
	5	5.123	5.126	5.031	2050	2048	2088
Natural material with 3/4" dense grades	1	5.112	5.445	5.423	2162	2031	2038
	2	5.634	5.490	5.407	1940	1990	2021
	3	5.423	5.533	5.481	2118	2075	2096
	4	5.606	5.496	5.592	2071	2107	2077
	5	5.094	5.174	5.197	2332	2288	2286
BOF slag with 1/2" dense grades	1	6.013	5.709	5.640	2101	2205	2240
	2	4.798	4.599	4.593	1907	1988	1992
	3	6.585	6.319	6.269	2489	2596	2615
	4	7.761	8.097	8.144	2397	2303	2284
	5	5.647	5.845	5.738	2557	2473	2516

TABLE X
MEASURED THICKNESS AND CALCULATED UNIT WEIGHT OF NATURAL MATERIAL WITH 1/2", 3/4" GRADES AND BOF SLAG WITH 3/4" DENSE GRADES OF DRILLED SPECIMEN AFTER CUTTING SURFACES

Types Of Specimen \ Measured Points		Measured Thickness (cm) 2	4	6	Calculated Unit Weight (kg/m^3) 2	4	6
Natural material with 1/2" dense grades	1	4.878	4.907	4.895	2221	2207	2214
	2	5.825	5.666	5.690	2172	2237	2224
	3	4.950	4.998	5.000	2294	2271	2271
	4	6.815	6.783	6.790	2163	2173	2171
	5	4.753	4.758	4.792	2210	2206	2192
Natural material with 3/4" dense grades	1	4.860	5.059	5.103	2274	2186	2166
	2	4.965	4.880	4.838	2201	2239	2259
	3	5.220	5.188	5.130	2201	2213	2239
	4	5.095	5.206	5.275	2279	2224	2201
	5	5.007	5.056	5.089	2373	2342	2334
BOF slag with 1/2" dense grades	1	4.609	4.757	4.803	2742	2645	2630
	2	3.384	3.396	3.456	2704	2693	2648
	3	6.066	5.900	5.894	2702	2780	2781
	4	6.800	7.112	7.140	2736	2622	2606
	5	5.058	5.063	4.981	2855	2855	2899

IV. CONCLUDING REMARKS

This paper presents one of the experimental methods for measurement of thickness and calculation of unit weight of specimen of asphalt concrete, i.e. the direct measurement method (DMM). Some concluding remarks are summarized as follows:

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 6, Issue 10, October 2016)

1. DMM offers the most easy and convenient way for measurement of thickness of asphalt concrete specimen. The averaged results obtained from 2-, 4- and 6-measurements on the Marshall samples are approximately equal and thus the same unit weights are obtained.
2. The unit weights calculated from thicknesses measured by DMM are based on the assumption that there exist no voids within the samples and this is not exactly true in actual condition. From the experiments the thicknesses measured from DMM are approximately higher than SSDWM about 0.06cm ~ 0.17cm, which leads to higher unit weights to 0.96%~2.46%.
3. Due to imperfection of bottom surface of drilled samples, the DMM results from 4- and 8-measurements contain 0.01 ~ 0.2 cm errors which lead to unit weight errors to 0.1% ~ 3.45%. Using the skill of cutting the bottom surface to be flat one the thickness difference can be exceeds 0.06 cm which causes 0.01% ~ 0.87% difference in unit weight estimation.

REFERENCES

[1] J. D. Lin. 1983. Mix Design and Principle of Asphalt Concretes, Tech Publisher. (in Chinese).

[2] J. D. Lin. 1997，Material Testing and Mix Design of Asphalt Concretes, QC Center, Institute of Civil Engineering, National Central University. (in Chinese).

[3] Public Works Committee, 2012. Concise Specification of Constructions: Chapter 02742: Asphalt Concrete Pavement. (in Chinese).

[4] C. C. Wang, 2005. Engineering Characteristics of Basic Oxygen Furnace (BOF) Slag and Used as Base Layer Materials, Ph. D. Thesis, Institute of Civil Engineering, National Cheng Kung University. (in Chinese).

[5] C. W. Yuan, 2007. The Study of Using BOF Steel Slag to Improve Perpetual Pavement Performance, Master Thesis, Institute of Civil Engineering, National Central University. (in Chinese).

[6] Y. T. Chang, 2008. Study on Basic Oxygen Furnace (BOF) Slag Applying for Recycled Asphalt Concrete, Master Thesis, Institute of Civil Engineering, National Ping-Tung University of Technology. (in Chinese).

[7] D. Huang, 2008. The Investigation on Effects of VMA Characteristics of Hot Mix Asphalt Using BOF Steel Slag Replacement for Natural Aggregates, Master Thesis, Institute of Civil Engineering, National Central University, (in Chinese).

[8] P. H. Wu, 2015. Effect of Basic Oxygen Furnace (BOF) Slag on Dense Grade Asphalt Concrete, Master Thesis, Institute of Civil Engineering, National Cheng Kung University. (in Chinese).

[9] W. C. Tsou, 2005. Feasibility of Measuring the Thickness of Asphalt Concrete Structures in Road Engineering Using Impact Echo Method, Master Thesis, Institute of Construction Engineering, Chao-Yang University of Technology. (in Chinese).

[10] M. Y. Hung, 2004. Application of Ground Penetration Radar to Measurement of Pavement Thickness of Asphalt Concrete. Master Thesis, Institute of Civil Engineering, Chung-Hwa University. (in Chinese).

[11] C. M. Huang, 2008. Investigation of Pavement Thickness and Void Existence Using Short-Pulse Ground Penetration Radar, Master Thesis, Institute of Construction Engineering, Chao-Yang University of Technology. (in Chinese).

[12] W. D. Cheng, 2009. Study on the Pavement Layer Thickness Evaluation Using Ground Penetration Radar, Master Thesis, Institute of Construction Engineering, Fung-Chia University. (in Chinese).

[13] L. S. Huang, and Y.V. Kang, 2010. Nondestructive Evaluation of Thickness and Bearing Capacity of Roadway Pavement Structure, International Journal of Pavement Research and Technology, Vol. 3, No. 6, pp. 311-319.

[14] Bureau of Standards, Metrology and Inspection, M.O.E.A., 1987，CNS-8755, Testing Methods for Thickness or Height of Compact Specimen of Mixtures of Asphalt Pavements. (in Chinese).

[15] F. M. Kuo, 2016. Effects of Different Methods on the Results of Unit Weight Tests for Asphalt Concrete, Master Thesis, Institute of Civil Engineering and Disaster Mitigation Technology, National Kaohsiung University of Applied Sciences. (in Chinese)

[16] Bureau of Standards, Metrology and Inspection, M.O.E.A., 1988，CNS-12395, Testing Method for Drag in Plastic Flow of Marshall Machine experiment of Asphalt Mixtures. (in Chinese).