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Influence of Different Methods on the Results of Unit Weight Tests for Asphalt Concrete: Part-IV: Comparative Study

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***Abstract*— Asphalt concrete has been vastly applied to be pavement material in highway engineering and many sustainable materials are attempted in replacement of aggregates for waste reduction. This research is proposed to adopt three experimental methods, including direct measurement method (DMM), saturated-surface dry weight method (SSDWM) and wax sealing method (WSM), to measure thickness and unit weight of AC samples. Two kinds of specimens, i.e., the Marshall specimens and drilled AC specimens with 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 presents the comparative study on the experimental results of these three methods and summarizes the important conclusion.**

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

I. INTRODUCTION

Pavements are important engineering structures for our everyday life, commerce and trade and are expected to be adequately strong and durable in their design life as well as function properly by providing a smooth traveling surface for the traffic under various conditions of environment. At first the pavement structure should be designed properly such that it has adequate thickness to resist excessive deformation under traffic loads [1].

It has been a long time for asphalt concrete (AC) pavements, acting as one of 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 [2, 3]. 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.

Mix design and structural design of AC pavements are interlinked and the purpose is to design optimal thickness and number of layer. Mix design is conducted mostly on the basis of volumetric properties of asphalt mixtures. Among them the thickness and bulk specific gravity (or unit weight) are the two fundamental measured quantities in the experiments.

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 [4]. 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 [5-9].

On the other hands, many techniques were also investigated and attempted for the measurement of thickness of pavement structures, such as impact echo method [10], ground penetration radar techniques [11-13] and non-destructive method [14]. However, these approaches are relatively high costly.

We sequentially employed the experimental approach by preparing Marshall Specimens and in-site drilling specimens, conducting three kinds of testing: (1) direct measurement method (DMM)[15]; (2) saturated-surface-dry weight method (SSDWM) [16]; and (3) wax sealing Method (WSM) [17]. This paper presents the final comparative study on the results for Marshall and drilled specimens with different mixtures using above three experimental methods.

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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" 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	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 ^{o}C Viscosity:135 ^{o}C	1970 (P) 3.9 (P)

B. Testing Variables

(1) Submerged time: Based on the specification of CNS8759 in the SSDWM of the research the measurement of the bulk specific gravity and density the difference of temperature of specimen and water is an important controlled parameter.
(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 impaction: considering three levels of equivalent single axle load (ESAL): heavy, medium and light, the corresponding number of impaction is 75, 50 and 35, respectively.

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 combination can be found in [18].

D. Associated Experimental Specifications and Standards

In USA for dense graded asphalt paving mixes, the bulk-specific gravity test can be run according to AASHTO T-166 (Bulk Specific Gravity of Compacted Hot Mix Asphalt Using Saturated Surface Dry Specimens); However, the specimens that contain open or voids or more than 2% water absorption can be tested by either ASTM-D-1188-96 (Bulk Specific Gravity and Density of Compacted Bituminous Mixtures Using Coated Samples) or AASHTO TP-69 (Bulk Specific Gravity and Density of Compacted Asphalt Mixtures Using Automatic Vacuum Sealing Method). Furthermore, for testing of field cores that obtained by sawing or coring the procedure is the same except that the dry mass is obtained last after drying the specimen at 110^{o}C to constant mass [1].

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In Taiwan, the following are employed:

(1) DMM: CNS-8755 [19]
(2) SSDWM: CNS-8759 [20]
(3) WSM: CNS-8757 [21]

E. Mixture Preparation

The procedures for preparing the mixture materials can be referred to [18] 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 [15].

F. Marshall Testing and Drilled Specimen Preparation

The specimen preparation for Marshall Testing are based on CNS 12395 specification and the detailed procedures can be followed as depicted in [22]. The preparation of drilled specimen is according to the specification CNS8755 [19]. We need to take one drilled specimen per 1000 m^2 AC pavement 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.

G. Experimental Methods

(1) DMM:

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

(a) 2-points:

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

(b) 4-points:

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

(c) 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.

(2) SSDWM:

The bulk specific gravity of SSDWM can be written as

$$SG = \frac{W_1}{W_2 - W_3} \tag{5}$$

where W_1, W_2, W_3 are defined as

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

$W_2 = weight\ of\ saturated\ surface - dry\ specimen\ in\ air,$

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

(3) WSM:

The bulk specific gravity of WSM can be written as

$$SG = \frac{W_1}{W_2 - W_3 - (W_2 - W_1)/G_{wax}} \tag{6}$$

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

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

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

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

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

The detailed procedures had been summarized in [15-18].

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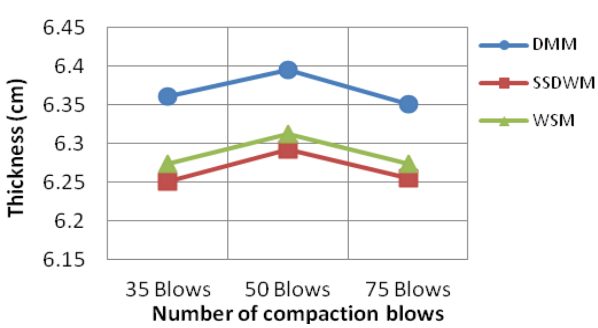
III. EXPERIMENTAL RESULTS

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

Table III and Fig. 1 show the results of measured thicknesses and unit weights, under different impact level, for natural material with 1/2" dense grades of Marshall Specimen using DMM, SSDWM and WSM. Results depict that values of thickness obtained using DMM are the highest among these three methods; while the unit weight obtained by DMM is the smallest which doesn't represent correct values as obtained using SSDWM and WSM which are based on principle of buoyancy. It is also observed that as the number of compaction blows increase, the measured unit weights become higher for the specimens using three methods.

TABLE III
MEASURED THICKNESS AND UNIT WEIGHT OF NATURAL MATERIAL WITH 1/2 " DENSE GRADES OF MARSHALL SPECIMEN USING 3 METHODS

Level Of Impact	Measured Quantities	Thickness (cm)			Unit Weight (kg/m^3)		
		DMM	SSDWM	WSM	DMM	SSDWM	WSM
75 Blows	1	6.342	6.221	6.238	2318	2362	2355
	2	6.341	6.243	6.264	2314	2352	2344
	3	6.363	6.280	6.302	2314	2345	2336
	4	6.364	6.279	6.298	2308	2342	2334
	5	6.343	6.253	6.269	2320	2354	2348
	Averaged	6.3506	6.2552	6.2742	2314.8	2351	2343.4
50 Blows	1	6.424	6.311	6.331	2278	2317	2310
	2	6.430	6.308	6.329	2273	2318	2310
	3	6.347	6.259	6.278	2305	2336	2329
	4	6.389	6.295	6.315	2284	2318	2310
	5	6.388	6.289	6.308	2288	2320	2313
	Averaged	6.3956	6.2924	6.3122	2285.6	2321.8	2314.4
35 Blows	1	6.383	6.271	6.293	2244	2286	2278
	2	6.395	6.283	6.304	2242	2284	2276
	3	6.368	6.255	6.275	2246	2288	2280
	4	6.346	6.221	6.246	2252	2299	2289
	5	6.314	6.225	6.248	2271	2302	2293
	Averaged	6.3612	6.251	6.2732	2251	2291.8	2283.2



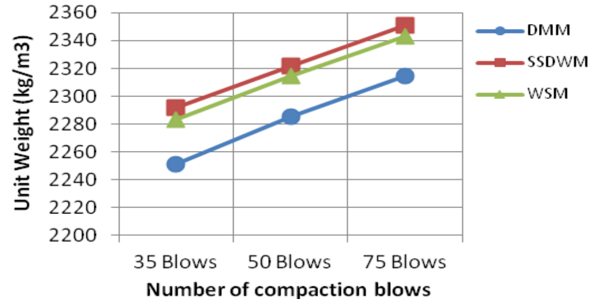


Figure 1 Averaged thickness and unit weight measurements for natural material with 1/2" dense grades of Marshall Specimen using DMM, SSDWM and WSM under different number of compaction blows

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

Table IV and Fig.2 depict the results of measured thicknesses and unit weights, under different impact level, for natural material with 3/4" dense grades of Marshall Specimen using DMM, SSDWM and WSM. The experimental results are similar with previous discussion. It should be noticed that the results of thickness and unit weight obtained from SSDWM and WSM are approximately the same. The reason that DMM provides highest thickness might come from the measurement of utmost thickness of specimen.

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

Level Of Impact	Measured Quantities	Thickness (cm)			Unit Weight (kg/m^3)		
		DMM	SSDWM	WSM	DMM	SSDWM	WSM
75 Blows	1	6.404	6.308	6.325	2345	2382	2376
	2	6.432	6.314	6.329	2327	2369	2363
	3	6.358	6.273	6.281	2353	2385	2382
	4	6.376	6.300	6.314	2347	2375	2370
	5	6.386	6.287	6.304	2346	2383	2376
	Averaged	6.3912	6.2964	6.3106	2343.6	2378.8	2373.4
50 Blows	1	6.356	6.251	6.266	2335	2374	2368
	2	6.444	6.304	6.311	2312	2362	2360
	3	6.369	6.281	6.307	2325	2360	2350
	4	6.367	6.309	6.324	2337	2357	2352
	5	6.375	6.285	6.302	2331	2366	2360
	Averaged	6.3822	6.286	6.302	2328	2363.8	2358
35 Blows	1	6.346	6.218	6.228	2283	2331	2327
	2	6.362	6.214	6.226	2271	2323	2318
	3	6.385	6.215	6.227	2262	2325	2320
	4	6.326	6.185	6.189	2290	2341	2340
	5	6.299	6.183	6.198	2292	2334	2328
	Averaged	6.3436	6.203	6.2136	2279.6	2330.8	2326.6

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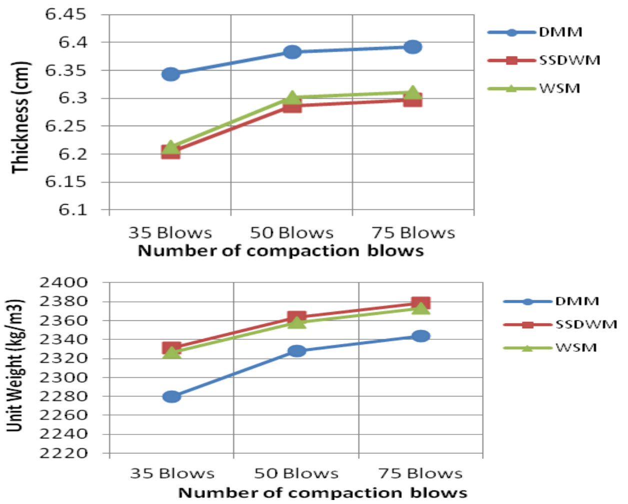

Figure 2 Averaged thickness and unit weight measurements for natural material with 3/4 " dense grades of Marshall Specimen using DMM, SSDWM and WSM under different number of compaction blows

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

Table V and Fig. 3 present the results of measured thicknesses and unit weigh, under different impact level, for natural material with 3/4" coarse grades of Marshall Specimen using DMM, SSDWM and WSM.

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

Level Of Impact	Measured Quantities	Thickness (cm) DMM	SSDWM	WSM	Unit Weight (kg/m^3) DMM	SSDWM	WSM
75 Blows	1	6.367	6.253	6.265	2299	2341	2337
	2	6.378	6.221	6.249	2295	2353	2343
	3	6.355	6.221	6.226	2298	2347	2346
	4	6.325	6.200	6.221	2314	2360	2352
	5	6.301	6.190	6.199	2317	2359	2356
	Averaged	6.3452	6.217	6.232	2304.6	2352	2346.8
50 Blows	1	6.375	6.267	6.280	2282	2324	2319
	2	6.402	6.251	6.268	2277	2330	2324
	3	6.426	6.285	6.294	2264	2315	2312
	4	6.341	6.215	6.232	2291	2339	2333
	5	6.394	6.237	6.264	2274	2332	2322
	Averaged	6.3876	6.251	6.2676	2277.6	2328	2322
35 Blows	1	6.356	6.229	6.242	2247	2294	2290
	2	6.323	6.175	6.192	2249	2304	2298
	3	6.384	6.214	6.221	2231	2290	2287
	4	6.344	6.226	6.238	2249	2292	2287
	5	6.413	6.264	6.269	2227	2280	2278
	Averaged	6.364	6.2216	6.2324	2240.6	2292	2288

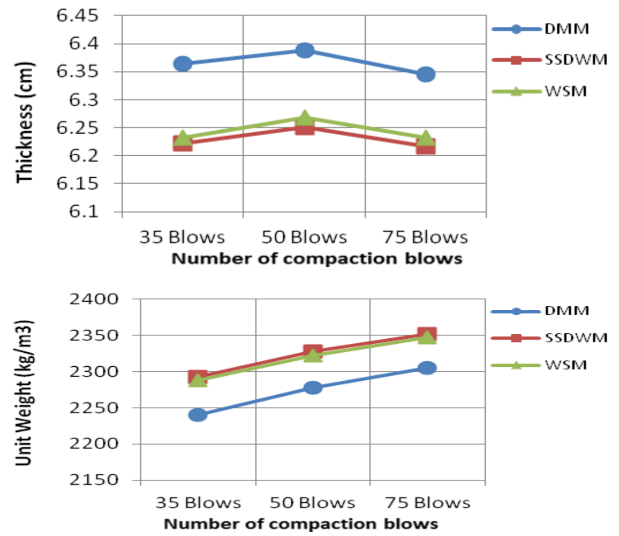

Figure 3 Averaged thickness and unit weight measurements for natural material with 3/4 " coarse grades of Marshall Specimen using DMM, SSDWM and WSM under different number of compaction blows

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

Table VI and Fig. 4 reveal the results of measured thicknesses and unit weights, under different impact level, for BOF slags with 1/2" dense grades of Marshall Specimen using DMM, SSDWM and WSM.

TABLE VI
MEASURED THICKNESS AND UNIT WEIGHT OF BOF SLAG WITH 1/2" DENSE GRADES OF MARSHALL SPECIMEN USING 3 METHODS

Level Of Impact	Measured Quantities	Thickness (cm) DMM	SSDWM	WSM	Unit Weight (kg/m^3) DMM	SSDWM	WSM
75 Blows	1	6.221	6.167	6.176	2611	2639	2636
	2	6.236	6.153	6.162	2605	2643	2640
	3	6.233	6.167	6.177	2598	2633	2629
	4	6.257	6.154	6.165	2598	2641	2636
	5	6.284	6.207	6.236	2587	2615	2603
	Averaged	6.2462	6.1696	6.1832	2599.8	2634.2	2628.8
50 Blows	1	6.363	6.287	6.297	2527	2564	2560
	2	6.295	6.205	6.221	2557	2599	2592
	3	6.354	6.254	6.266	2554	2584	2580
	4	6.319	6.241	6.252	2550	2587	2583
	5	6.305	6.221	6.226	2556	2595	2593
	Averaged	6.3272	6.2416	6.2524	2548.8	2585.8	2581.6
35 Blows	1	6.284	6.200	6.217	2523	2558	2551
	2	6.245	6.148	6.162	2544	2583	2577
	3	6.263	6.167	6.183	2532	2575	2569
	4	6.244	6.180	6.189	2540	2566	2563
	5	6.293	6.185	6.206	2525	2568	2559
	Averaged	6.2658	6.176	6.1914	2532.8	2570	2563.8

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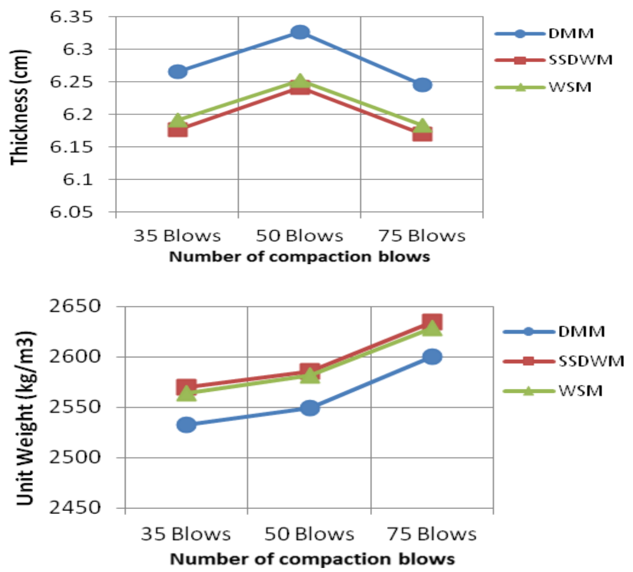

Figure 4 Averaged thickness and unit weight measurements for BOF sslag with 1/2" dense grades of Marshall Specimen using DMM, SSDWM and WSM under different number of compaction blows

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

Table VII and Fig.5 show the results of measured thicknesses and unit weights, under different impact level, for BOF slags with 3/4" dense grades of Marshall Specimen using DMM, SSDWM and WSM.

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

Level Of Impact \ Measured Quantities		Thickness (cm) DMM	Thickness (cm) SSDWM	Thickness (cm) WSM	Unit Weight (kg/m^3) DMM	Unit Weight (kg/m^3) SSDWM	Unit Weight (kg/m^3) WSM
75 Blows	1	6.428	6.351	6.362	2639	2676	2672
	2	6.450	6.339	6.347	2653	2684	2681
	3	6.442	6.366	6.374	2654	2679	2675
	4	6.432	6.376	6.381	2629	2664	2662
	5	6.470	6.370	6.384	2635	2673	2668
	Averaged	6.4444	6.3604	6.3696	2642	2675.2	2671.6
50 Blows	1	6.380	6.311	6.314	2601	2628	2625
	2	6.348	6.292	6.307	2603	2633	2627
	3	6.343	6.244	6.243	2599	2648	2648
	4	6.303	6.215	6.231	2618	2659	2652
	5	6.267	6.206	6.215	2632	2662	2658
	Averaged	6.3282	6.2536	6.262	2610.6	2646	2642
35 Blows	1	6.291	6.219	6.226	2561	2594	2591
	2	6.299	6.224	6.248	2561	2588	2578
	3	6.276	6.216	6.237	2587	2591	2583
	4	6.245	6.156	6.176	2579	2621	2613
	5	6.298	6.192	6.220	2551	2598	2587
	Averaged	6.2818	6.2014	6.2214	2567.8	2598.4	2590.4

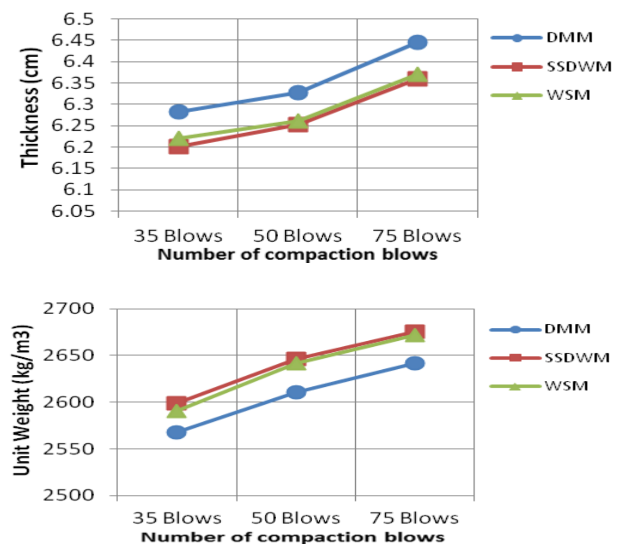

Figure 5 Averaged thickness and unit weight measurements for BOF slag with 3/4" dense grades of Marshall Specimen using DMM, SSDWM and WSM under different number of compaction blows

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

We can realize from Table VIII and Fig. 6 the results of measured thicknesses and unit weights, under different impact level, for BOF slags with 3/4" coarse grades of Marshall Specimen using DMM, SSDWM and WSM.

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

Level Of Impact \ Measured Quantities		Thickness (cm) DMM	Thickness (cm) SSDWM	Thickness (cm) WSM	Unit Weight (kg/m^3) DMM	Unit Weight (kg/m^3) SSDWM	Unit Weight (kg/m^3) WSM
75 Blows	1	6.293	6.162	6.179	2622	2680	2672
	2	6.362	6.245	6.260	2613	2652	2645
	3	6.342	6.285	6.293	2611	2631	2628
	4	6.345	6.258	6.270	2608	2644	2639
	5	6.383	6.287	6.299	2608	2640	2636
	Averaged	6.345	6.2474	6.2602	2612.4	2649.4	2644
50 Blows	1	6.344	6.298	6.306	2593	2621	2613
	2	6.388	6.342	6.359	2571	2594	2588
	3	6.418	6.319	6.333	2562	2600	2594
	4	6.373	6.313	6.334	2565	2599	2590
	5	6.299	6.218	6.237	2605	2639	2631
	Averaged	6.3644	6.298	6.3138	2579.2	2610.6	2603.2
35 Blows	1	6.450	6.383	6.405	2549	2580	2571
	2	6.379	6.286	6.319	2561	2599	2586
	3	6.362	6.284	6.316	2558	2594	2580
	4	6.384	6.303	6.340	2557	2592	2577
	5	6.377	6.289	6.317	2561	2596	2584
	Averaged	6.3904	6.309	6.3394	2557.2	2592.2	2579.6

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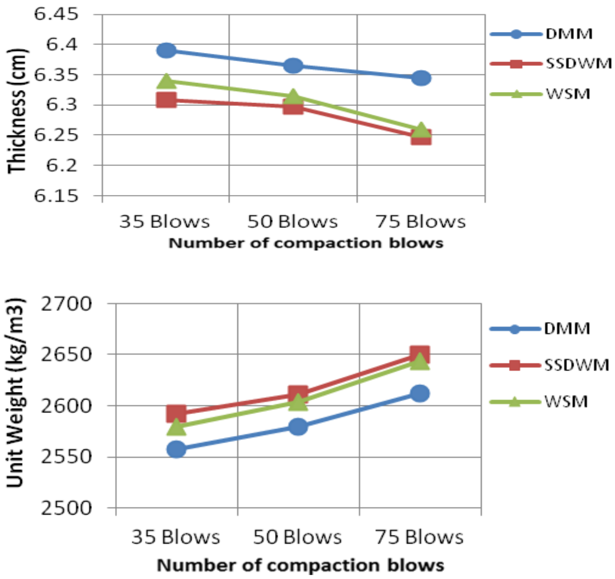

Figure 6 Averaged thickness and unit weight measurements for BOF slag with 3/4" coarse grades of Marshall Specimen using DMM, SSDWM and WSM under different number of compaction blows

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

It is noticed that for testing of field cores that obtained by sawing or coring the procedure is the same except that the dry mass is obtained last after drying the specimen at 110°C to constant mass. The drilled specimens are usually with cracks and holes due to pavement compaction. If there exist many the holes of surface and WSM is employed the measured unit weight might be lower than those obtained from SSDWM.

Table IX shows the results of measured thicknesses and unit weights, under different impact level, for natural material with 1/2", 3/4" dense grades and BOF slag with 1/2" dense grade of drilled specimen using DMM, SSDWM and WSM.

It can be shown that in Figure 8 the averaged thickness and unit weights of BOF slag with 1/2" dense grades depict the highest values among these three specimens. This shows the benefit of using BOF steel slag in replacement of natural aggregates for AC pavement application.

Furthermore, as compared with those results obtained from Marshall Specimens, the three methods provide similar values for measured thickness and unit weight. The reason requires further detailed study on the correlation analysis.

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

Types Of Specimen \ Measured Quantities		Thickness (cm)			Unit Weight (kg/m^3)		
		DMM	SSDWM	WSM	DMM	SSDWM	WSM
Natural material with 1/2" dense grade	1	4.878	4.874	4.894	2221	2222	2213
	2	5.825	5.707	5.720	2172	2221	2216
	3	4.950	4.963	4.999	2294	2287	2271
	4	6.815	6.718	6.746	2163	2193	2184
	5	4.753	4.674	4.687	2210	2246	2240
	Averaged	5.4442	5.3872	5.4092	2212	2233.8	2224.8
Natural material with 3/4" dense grade	1	4.860	4.978	4.998	2274	2221	2212
	2	4.965	4.801	4.804	2201	2276	2274
	3	5.220	5.057	5.076	2201	2270	2262
	4	5.095	5.125	5.128	2279	2259	2258
	5	5.007	4.968	4.981	2373	2383	2377
	Averaged	5.0294	4.9858	4.9974	2265.6	2281.8	2276.6
BOF slag with 1/2" dense grade	1	4.609	4.584	4.604	2742	2746	2734
	2	3.384	3.312	3.319	2704	2761	2755
	3	6.066	5.774	5.797	2702	2841	2830
	4	6.800	7.053	7.113	2736	2644	2621
	5	5.058	4.992	5.027	2855	2895	2875
	Averaged	5.1834	5.143	5.172	2747.8	2777.4	2763

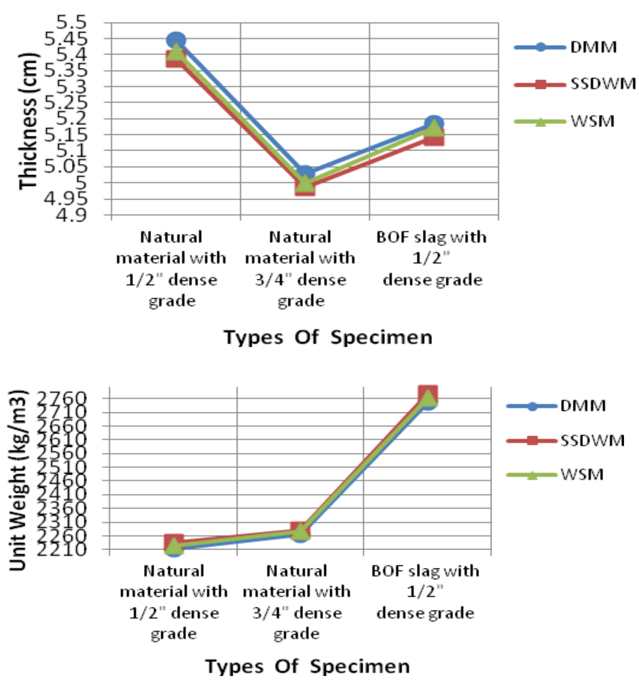

Figure 8 Averaged thickness and unit weight measurements for drilled specimens made of three different mixtures using DMM, SSDWM and WSM.

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IV. CONCLUDING REMARKS

Totally three methods were employed for measuring thickness and unit weight of Marshall and drilled AC specimens using different mixtures for pavement application. The three methods are DMM, SSDWM and WSM. This paper summarizes the overall important comparative results of thickness and unit weight using these three experimental methods. Some concluding remarks can be elucidated as follows:

1. For Marshall specimens and drilled samples DMM gives the highest values of thickness but the lowest values of unit weight among these three methods and thus can be employed to provide a quick preliminary reference.
2. As the number of compaction blows increase the measured unit weights obtained for all the Marshall specimens using different mixtures and different methods. This is reasonable since AC with higher unit weight design with higher ESAL requirement which is associated with higher compaction.
3. Among the three experimental approaches SSDWM is mainly recommended for Marshall and drilled specimens while WSM is suggested when the surface of specimens contains many holes especially obtained from drilling.
4. All the three methods reveal that 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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