International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 6, Issue 11, November 2016)

Influence of Different Methods on the Results of Unit Weight Tests for Asphalt Concrete: Part-II: Saturated-Surface-Dry Weight Method

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***Abstract*— Asphalt concrete has been applied to pavement material for a long time and there are many sustainable materials are attempted in replacement of aggregates for waste reduction. However, accurate measurement of unit weight of AC specimen is important for quality control. In practice only saturated-surface-dry weight method (SSDWM) was usually adopted in experiments, but not the wax sealing method (WSM) and direct measurement method (DMM) This study is proposed to adopt 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 presents the Part II, i.e. saturated-surface-dry weight method (SSDWM)**

***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 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 [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. 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 can be referred [4-8].

However, in recent years 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 general the state of water content in aggregates can be divided into four degrees: (1) oven dry (O.D.); (2) air dry (A.D.); (3) saturated surface-dry (S.S.D.); and (4) wet. In this research we employed the experimental approach by preparing the Marshall specimens 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 presents the process and results of Part II, i.e. saturated-surface-dry weight method (SSDWM).

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.

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 6, Issue 11, November 2016)

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 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) 39 (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 compaction blows: considering three levels of equivalent single axle load (ESAL): heavy, medium and light, the corresponding number of compaction blows 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 [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 of [17].

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 Method

The bulk specific gravity of SSDWM can be written as

$$SG = \frac{W_1}{W_2 - W_3} \tag{1}$$

where W_1, W_2, W_3 are defined as

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

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

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

The detailed procedures had been summarized in [15]. It should be noticed that in the experiments using SSDWM we should consider the following three specimens:

(1) Specimen containing water;
(2) Specimen containing water and solvent;
(3) Specimen containing no water (absolutely dried).

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 6, Issue 11, November 2016)

III. Experimental Results

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

Table III and IV show the results of measured thicknesses and unit weights, at different time, for natural material with 1/2" dense grades of Marshall specimen using SSDWM. CNS 8759 specification is satisfied for these specimens [14]. Results depict that there is little difference for various time of submerged in water. Averaged unit weights of 5 specimens under three level of compaction are 2352, 2324 and 2293 kg/m^3 for 75, 50 and 35 blowss, respectively after 24 hours..

It can be observed from Figure 1 that unit weight obtained for all the three levels of compaction blows depict approximately the same time variation, i.e. they are almost constant with time. However, the higher level of compaction blows the higher unit weight obtained as expected.

TABLE III
MEASURED THICKNESS OF NATURAL MATERIAL WITH 1/2 " DENSE GRADES OF THE MARSHALL SPECIMENS USING SSDWM

Types Of Specimen \ Measured Time		Thickness at different time (cm)					
		3 min	5 min	10 min	15 min	30 min	24 hr
75 Blows	1	6.230	6.226	6.221	6.216	6.217	6.227
	2	6.246	6.248	6.243	6.248	6.238	6.242
	3	6.286	6.282	6.280	6.277	6.280	6.271
	4	6.279	6.280	6.279	6.274	6.271	6.267
	5	6.253	6.250	6.253	6.245	6.245	6.245
	Averaged	6.2588	6.2572	6.2552	6.252	6.2502	6.2504
50 Blows	1	6.316	6.315	6.311	6.318	6.305	6.305
	2	6.309	6.313	6.308	6.306	6.304	6.302
	3	6.272	6.270	6.259	6.256	6.248	6.258
	4	6.296	6.296	6.295	6.296	6.291	6.287
	5	6.293	6.294	6.289	6.287	6.287	6.283
	Averaged	6.2972	6.2976	6.2924	6.2926	6.287	6.287
35 Blows	1	6.272	6.272	6.271	6.267	6.264	6.264
	2	6.288	6.285	6.283	6.288	6.289	6.288
	3	6.251	6.254	6.255	6.253	6.248	6.255
	4	6.212	6.221	6.221	6.216	6.211	6.214
	5	6.229	6.226	6.225	6.221	6.220	6.220
	Averaged	6.2504	6.2516	6.251	6.249	6.2464	6.2482

TABLE IV
MEASURED UNIT WEIGHT OF NATURAL MATERIAL WITH 1/2 " DENSE GRADES OF THE MARSHALL SPECIMENS USING SSDWM

Types Of Specimen \ Measured Time		Unit weight at different time (kg/m^3)					
		3 min	5 min	10 min	15 min	30 min	24 hr
75 Blows	1	2358	2360	2362	2364	2363	2359
	2	2351	2350	2352	2350	2354	2352
	3	2342	2344	2345	2345	2345	2348
	4	2342	2341	2342	2344	2345	2346
	5	2354	2355	2354	2357	2357	2357
	Averaged	2349.4	2350	2351	2352	2352.8	2352.4
50 Blows	1	2315	2316	2317	2315	2319	2319
	2	2317	2316	2318	2318	2319	2320
	3	2331	2332	2336	2337	2341	2337
	4	2317	2317	2318	2317	2319	2320
	5	2318	2318	2320	2321	2321	2322
	Averaged	2319.6	2319.8	2321.8	2321.6	2323.8	2323.6
35 Blows	1	2285	2285	2286	2287	2288	2288
	2	2282	2283	2284	2282	2282	2282
	3	2289	2288	2288	2288	2290	2288
	4	2302	2299	2299	2300	2302	2301
	5	2300	2301	2302	2303	2304	2304
	Averaged	2291.6	2291.2	2291.8	2292	2293.2	2292.6

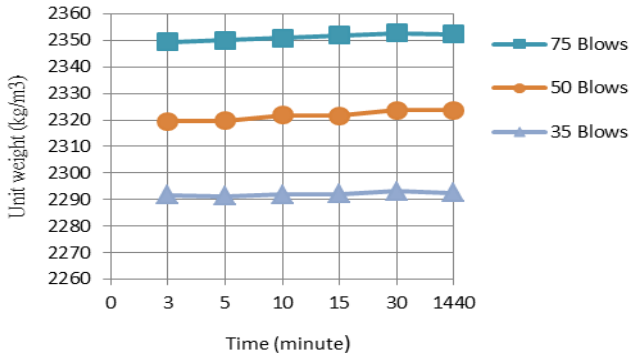

Figure 1 Effect of submerged time on the averaged unit weight measurements for natural material with 1/2 " dense grades of the Marshall specimens using SSDWM under different compaction blows

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

Table V and VI depict the results of measured thicknesses and unit weights, at different time, for natural material with 3/4" dense grades of Marshall specimen using SSDWM.

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International Journal of Emerging Technology and Advanced Engineering
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Figure 2 shows unit weight obtained for three levels of impact are almost constant with time. However, the higher level of impact the higher unit weight obtained as expected.

Table V
Measured Thickness Of Natural Material With 3/4 " Dense Grades Of The Marshall Specimens Using SSDWM

Types Of Specimen \ Measured Time		Thickness at different time (cm)					
		3 min	5 min	10 min	15 min	30 min	24 hr
75 Blows	1	6.317	6.312	6.308	6.318	6.305	6.310
	2	6.315	6.308	6.314	6.316	6.305	6.321
	3	6.271	6.272	6.273	6.263	6.268	6.267
	4	6.305	6.304	6.300	6.299	6.297	6.303
	5	6.291	6.291	6.287	6.285	6.284	6.291
	Averaged	6.2998	6.2974	6.2964	6.2962	6.2918	6.2984
50 Blows	1	6.256	6.251	6.251	6.251	6.242	6.245
	2	6.306	6.297	6.304	6.309	6.292	6.295
	3	6.279	6.281	6.281	6.280	6.284	6.296
	4	6.306	6.304	6.309	6.299	6.299	6.299
	5	6.285	6.281	6.285	6.282	6.276	6.277
	Averaged	6.2864	6.2828	6.286	6.2842	6.2786	6.2824
35 Blows	1	6.215	6.213	6.218	6.217	6.206	6.212
	2	6.211	6.216	6.214	6.219	6.205	6.211
	3	6.211	6.219	6.215	6.214	6.214	6.214
	4	6.183	6.185	6.185	6.179	6.177	6.180
	5	6.182	6.177	6.183	6.174	6.171	6.168
	Averaged	6.2004	6.202	6.203	6.2006	6.1946	6.197

Table VI
Measured Unit Weight Of Natural Material With 3/4 " Dense Grades Of The Marshall Specimens Using SSDWM

Types Of Specimen \ Measured Time		Unit weight at different time (kg/m^3)					
		3 min	5 min	10 min	15 min	30 min	24 hr
75 Blows	1	2379	2381	2382	2379	2384	2382
	2	2368	2371	2369	2368	2372	2366
	3	2386	2385	2385	2389	2387	2387
	4	2373	2373	2375	2375	2376	2374
	5	2381	2381	2383	2383	2384	2381
	Averaged	2377.4	2378.2	2378.8	2378.8	2380.6	2378
50 Blows	1	2372	2374	2374	2374	2377	2376
	2	2361	2365	2362	2360	2367	2366
	3	2361	2360	2360	2360	2359	2354
	4	2358	2359	2357	2361	2361	2361
	5	2366	2368	2366	2367	2370	2369
	Averaged	2363.6	2365.2	2363.8	2364.4	2366.8	2365.2
35 Blows	1	2332	2326	2331	2331	2336	2333
	2	2324	2322	2323	2321	2326	2324
	3	2326	2323	2325	2325	2325	2325
	4	2342	2341	2341	2344	2345	2343
	5	2334	2336	2334	2337	2339	2340
	Averaged	2331.6	2329.6	2330.8	2331.6	2334.2	2333

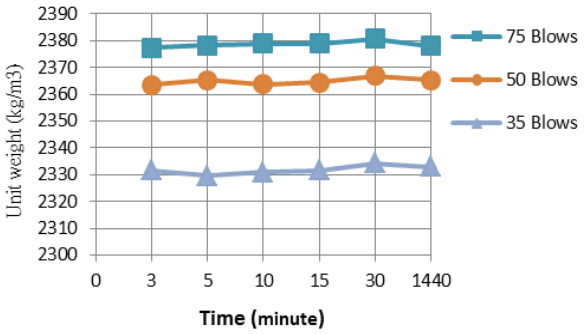

Figure 2 Effect of submerged time on the averaged unit weight measurements for natural material with 3/4 " dense grades of the Marshall specimens using SSDWM under different compaction blows

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

Table VII and VIII present the results of measured thicknesses and unit weight, at different time, for natural material with 3/4" coarse grades of Marshall Specimen. Figure 3 depicts the averaged results.

Table VII
Measured Thickness Of Natural Material With 3/4 " Coarse Grades Of The Marshall Specimens Using SSDWM

Types Of Specimen \ Measured Time		Thickness at different time (cm)					
		3 min	5 min	10 min	15 min	30 min	24 hr
75 Blows	1	6.257	6.250	6.253	6.255	6.242	6.247
	2	6.231	6.226	6.221	6.224	6.215	6.221
	3	6.226	6.225	6.221	6.211	6.214	6.214
	4	6.201	6.204	6.200	6.198	6.194	6.198
	5	6.195	6.192	6.190	6.185	6.182	6.190
	Averaged	6.222	6.2194	6.217	6.2146	6.2094	6.214
50 Blows	1	6.266	6.258	6.267	6.268	6.251	6.257
	2	6.246	6.246	6.251	6.257	6.252	6.243
	3	6.275	6.289	6.285	6.278	6.273	6.278
	4	6.217	6.222	6.215	6.221	6.214	6.222
	5	6.234	6.237	6.237	6.237	6.237	6.238
	Averaged	6.2476	6.2504	6.251	6.2522	6.2454	6.2476
35 Blows	1	6.224	6.227	6.229	6.228	6.223	6.224
	2	6.169	6.172	6.175	6.175	6.167	6.169
	3	6.206	6.204	6.214	6.206	6.206	6.209
	4	6.217	6.226	6.226	6.226	6.215	6.222
	5	6.258	6.262	6.264	6.258	6.256	6.248
	Averaged	6.2148	6.2182	6.2216	6.2186	6.2134	6.2144

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 6, Issue 11, November 2016)

Table VIII
Measured Unit Weight Of Natural Material With 3/4 " Coarse Grades Of The Marshall Specimens Using SSDWM

Types Of Specimen	Measured Time	Unit weight at different time (kg/m^3) 3 min	5 min	10 min	15 min	30 min	24 hr
75 Blows	1	2340	2342	2341	2341	2345	2343
	2	2350	2352	2353	2352	2356	2353
	3	2345	2346	2347	2351	2350	2350
	4	2359	2358	2360	2360	2362	2360
	5	2358	2359	2359	2361	2362	2359
	Averaged	2350.4	2351.4	2352	2353	2355	2353
50 Blows	1	2324	2327	2324	2323	2330	2328
	2	2332	2332	2330	2328	2330	2333
	3	2319	2314	2315	2318	2320	2318
	4	2338	2337	2339	2337	2340	2337
	5	2333	2332	2332	2332	2332	2331
	Averaged	2329.2	2328.4	2328	2327.6	2330.4	2329.4
35 Blows	1	2296	2295	2294	2295	2297	2296
	2	2306	2305	2304	2304	2307	2306
	3	2292	2293	2290	2292	2292	2292
	4	2295	2292	2292	2292	2296	2293
	5	2282	2281	2280	2282	2283	2286
	Averaged	2294.2	2293.2	2292	2293	2295	2294.6

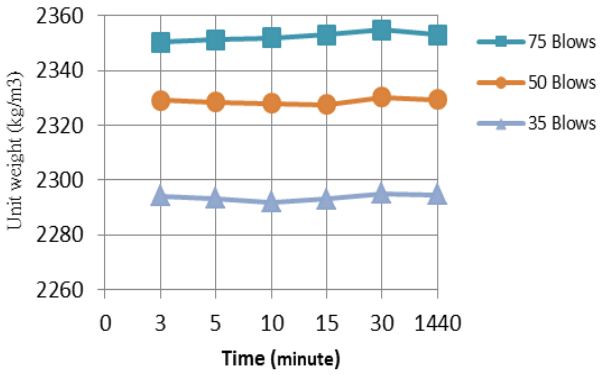

Figure 3 Effect of submerged time on the averaged unit weight measurements for natural material with 3/4 " coarse grades of the Marshall specimens using SSDWM under different compaction blows

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

Table IX and X reveals the results of measured thicknesses and unit weights, at different duration, for BOF slags with 1/2" dense grades of the Marshall specimens. Furthermore, averaged unit weight measurements at different time are shown in Figure 4.

Table IX
Measured Thickness Of BOF Slag With 1/2" Dense Grades Of The Marshall Specimens Using SSDWM

Types Of Specimen	Measured Time	Thickness at different time (cm) 3 min	5 min	10 min	15 min	30 min	24 hr
75 Blows	1	6.172	6.165	6.167	6.163	6.160	6.160
	2	6.159	6.149	6.153	6.152	6.149	6.146
	3	6.167	6.169	6.167	6.165	6.164	6.160
	4	6.158	6.148	6.154	6.148	6.146	6.148
	5	6.215	6.206	6.207	6.207	6.209	6.209
	Averaged	6.1742	6.1674	6.1696	6.167	6.1656	6.1646
50 Blows	1	6.288	6.282	6.287	6.284	6.276	6.270
	2	6.209	6.208	6.205	6.204	6.203	6.199
	3	6.261	6.262	6.254	6.256	6.257	6.251
	4	6.241	6.238	6.241	6.232	6.232	6.232
	5	6.219	6.223	6.221	6.218	6.212	6.209
	Averaged	6.2436	6.2426	6.2416	6.2388	6.236	6.2322
35 Blows	1	6.205	6.196	6.200	6.200	6.191	6.188
	2	6.154	6.153	6.148	6.147	6.143	6.141
	3	6.193	6.190	6.167	6.187	6.187	6.183
	4	6.177	6.177	6.180	6.169	6.170	6.170
	5	6.184	6.186	6.185	6.176	6.180	6.176
	Averaged	6.1826	6.1804	6.176	6.1758	6.1742	6.1716

Table X
Measured Unit Weight Of BOF Slag With 1/2" Dense Grades Of The Marshall Specimens Using SSDWM

Types Of Specimen	Measured Time	Unit weight at different time (kg/m^3) 3 min	5 min	10 min	15 min	30 min	24 hr
75 Blows	1	2637	2640	2639	2641	2642	2642
	2	2641	2645	2643	2644	2645	2647
	3	2633	2632	2633	2634	2634	2636
	4	2640	2644	2641	2644	2645	2644
	5	2612	2616	2615	2615	2615	2615
	Averaged	2632.6	2635.4	2634.2	2635.6	2636.2	2636.8
50 Blows	1	2564	2566	2564	2566	2569	2571
	2	2597	2598	2599	2600	2600	2602
	3	2582	2581	2584	2584	2583	2586
	4	2587	2588	2587	2591	2591	2591
	5	2596	2594	2595	2596	2599	2600
	Averaged	2585.2	2585.4	2585.8	2587.4	2588.4	2590
35 Blows	1	2556	2559	2558	2558	2561	2563
	2	2580	2581	2583	2584	2585	2586
	3	2565	2566	2575	2567	2567	2569
	4	2568	2568	2566	2571	2570	2570
	5	2568	2567	2568	2571	2570	2571
	Averaged	2567.4	2568.2	2570	2570.2	2570.6	2571.8

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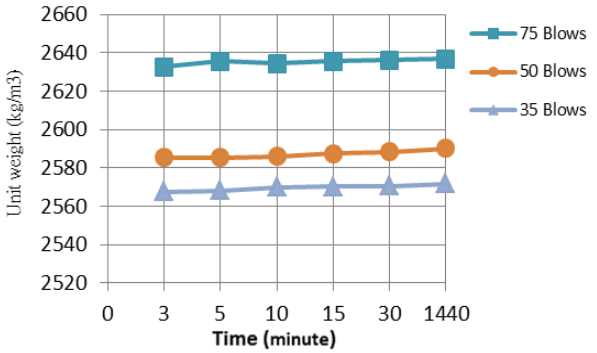

Figure 4 Effect of submerged time on the averaged unit weight measurements for BOF sslag with 1/2" dense grades of the Marshall specimens using SSDWM under different compaction blows

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

It can be observed from Table XI and XII the results of measured thicknesses and unit weights, at different time duration, for BOF slags with 3/4" dense grades of Marshall Specimen. We can also observe in Figure 5 the averaged results of unit weight measurements.

TABLE XI
MEASURED THICKNESS OF BOF SLAG WITH 3/4" DENSE GRADES OF THE MARSHALL SPECIMENS USING SSDWM

Types Of Specimen \ Measured Time		Thickness at different time (cm)					
		3 min	5 min	10 min	15 min	30 min	24 hr
75 Blows	1	6.360	6.350	6.351	6.355	6.352	6.350
	2	6.341	6.337	6.339	6.342	6.340	6.337
	3	6.366	6.366	6.366	6.361	6.360	6.358
	4	6.379	6.374	6.376	6.371	6.369	6.371
	5	6.376	6.378	6.370	6.365	6.376	6.364
	Averaged	6.3644	6.361	6.3604	6.3588	6.3594	6.356
50 Blows	1	6.311	6.300	6.311	6.303	6.300	6.297
	2	6.296	6.292	6.292	6.293	6.286	6.284
	3	6.238	6.243	6.244	6.239	6.233	6.229
	4	6.222	6.219	6.215	6.205	6.212	6.210
	5	6.206	6.206	6.206	6.204	6.204	6.202
	Averaged	6.2546	6.252	6.2536	6.2488	6.247	6.2444
35 Blows	1	6.219	6.216	6.219	6.214	6.211	6.211
	2	6.228	6.226	6.224	6.220	6.219	6.224
	3	6.221	6.219	6.216	6.211	6.210	6.207
	4	6.160	6.158	6.156	6.153	6.154	6.151
	5	6.201	6.202	6.192	6.195	6.197	6.193
	Averaged	6.2058	6.2042	6.2014	6.1986	6.1982	6.1972

TABLE XII
MEASURED UNIT WEIGHT OF BOF SLAG WITH 3/4" DENSE GRADES OF THE MARSHALL SPECIMENS USING SSDWM

Types Of Specimen \ Measured Time		Unit weight at different time (kg/m^3)					
		3 min	5 min	10 min	15 min	30 min	24 hr
75 Blows	1	2672	2677	2676	2674	2675	2677
	2	2683	2684	2684	2682	2683	2684
	3	2679	2679	2679	2681	2682	2682
	4	2663	2665	2664	2666	2667	2666
	5	2671	2670	2673	2676	2673	2676
	Averaged	2673.6	2675	2675.2	2675.8	2676	2677
50 Blows	1	2626	2631	2628	2630	2631	2632
	2	2632	2633	2633	2633	2636	2637
	3	2650	2648	2648	2650	2652	2654
	4	2656	2657	2659	2663	2660	2661
	5	2662	2662	2662	2663	2663	2663
	Averaged	2645.2	2646.2	2646	2647.8	2648.4	2649.4
35 Blows	1	2594	2595	2594	2596	2597	2597
	2	2587	2587	2588	2590	2590	2588
	3	2589	2586	2591	2593	2594	2595
	4	2619	2621	2621	2623	2622	2623
	5	2595	2594	2598	2597	2596	2598
	Averaged	2596.8	2596.6	2598.4	2599.8	2599.8	2600.2

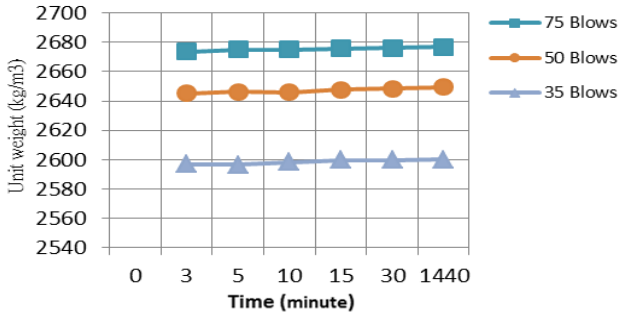

Figure 5 Effect of submerged time on the averaged unit weight measurements for BOF slag with 3/4" dense grades of the Marshall specimens using SSDWM under different compaction blows

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

We can realize from Table XIII and XIV the results of measured thicknesses and unit weights, at different time, for BOF slags with 3/4" coarse grades of Marshall Specimen. The averaged quantities of unit weight measurement under different number of impact can be observed in Figure 6. Figure 7 shows the condition of coarse aggregates submerged in water.

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 6, Issue 11, November 2016)

TABLE XIII
MEASURED THICKNESS OF BOF SLAG WITH 3/4" COARSE GRADES OF THE MARSHALL SPECIMENS USING SSDWM

Types Of Specimen \ Measured Time		Thickness at different time (cm) 3 min	5 min	10 min	15 min	30 min	24 hr
75 Blows	1	6.169	6.162	6.162	6.163	6.157	6.158
	2	6.246	6.242	6.245	6.245	6.237	6.240
	3	6.282	6.286	6.285	6.277	6.272	6.280
	4	6.257	6.258	6.258	6.257	6.253	6.252
	5	6.303	6.291	6.287	6.285	6.284	6.269
	Averaged	6.2514	6.2478	6.2474	6.2454	6.2406	6.2398
50 Blows	1	6.303	6.293	6.298	6.292	6.289	6.289
	2	6.344	6.339	6.342	6.340	6.336	6.337
	3	6.316	6.320	6.319	6.314	6.314	6.315
	4	6.321	6.318	6.313	6.313	6.309	6.311
	5	6.223	6.218	6.218	6.216	6.216	6.217
	Averaged	6.3014	6.2976	6.298	6.295	6.2928	6.2938
35 Blows	1	6.383	6.382	6.383	6.378	6.373	6.391
	2	6.289	6.285	6.286	6.285	6.284	6.287
	3	6.286	6.290	6.284	6.281	6.280	6.286
	4	6.298	6.300	6.303	6.315	6.292	6.303
	5	6.290	6.294	6.289	6.283	6.289	6.293
	Averaged	6.3092	6.3102	6.309	6.3084	6.3036	6.312

TABLE XIV
MEASURED UNIT WEIGHT OF BOF SLAG WITH 3/4" COARSE GRADES OF THE MARSHALL SPECIMENS USING SSDWM

Types Of Specimen \ Measured Time		Unit weight at different time (kg/m^3) 3 min	5 min	10 min	15 min	30 min	24 hr
75 Blows	1	2677	2680	2680	2679	2682	2681
	2	2651	2653	2652	2652	2655	2654
	3	2633	2631	2631	2635	2637	2634
	4	2645	2644	2644	2645	2646	2647
	5	2634	2639	2640	2641	2642	2648
	Averaged	2648	2649.4	2649.4	2650.4	2652.4	2652.8
50 Blows	1	2614	2618	2621	2619	2620	2620
	2	2594	2596	2594	2595	2597	2596
	3	2601	2599	2600	2602	2602	2601
	4	2595	2596	2599	2599	2600	2600
	5	2637	2639	2639	2640	2640	2639
	Averaged	2608.2	2609.6	2610.6	2611	2611.8	2611.2
35 Blows	1	2580	2581	2580	2582	2584	2577
	2	2598	2600	2599	2600	2600	2599
	3	2591	2591	2594	2595	2595	2593
	4	2592	2593	2593	2592	2597	2592
	5	2595	2594	2596	2598	2596	2594
	Averaged	2591.2	2591.8	2592.4	2593.4	2594.4	2591

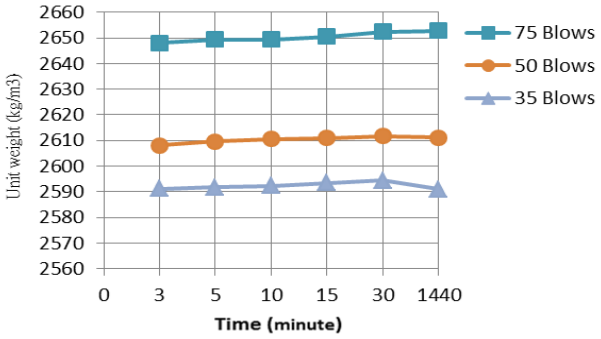

Figure 6 Effect of submerged time on the averaged unit weight measurements for BOF slag with 3/4" coarse grades of the Marshall specimens using SSDWM under different compaction blows

Figure 7 Coarse aggregates submerged in water

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 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.

We can identify from Table XV and XVI, respectively, the results of measured thicknesses and unit weights, at different time, 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 8 the averaged 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.

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 6, Issue 11, November 2016)

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

Types Of Specimen \ Measured Time		Thickness at different time (cm) 3 min	5 min	10 min	15 min	30 min	24 hr
Natural material with 1/2" dense grade	1	4.881	4.875	4.874	4.869	4.874	4.873
	2	5.709	5.707	5.707	5.709	5.707	5.712
	3	4.967	4.964	4.963	4.964	4.961	4.963
	4	6.716	6.720	6.718	6.705	6.714	6.714
	5	4.677	4.674	4.674	4.673	4.670	4.670
	Averaged	5.39	5.388	5.3872	5.384	5.3852	5.3864
Natural material with 3/4" dense grade	1	4.976	4.969	4.978	4.971	4.976	4.974
	2	4.798	4.793	4.801	4.799	4.793	4.795
	3	5.065	5.063	5.057	5.062	5.063	5.061
	4	5.127	5.127	5.125	5.121	5.117	5.125
	5	4.969	4.966	4.968	4.970	4.970	4.972
	Averaged	4.987	4.9836	4.9858	4.9846	4.9838	4.9854
BOF slag with 1/2" dense grade	1	4.591	4.584	4.584	4.582	4.581	4.577
	2	3.314	3.309	3.312	3.312	3.311	3.312
	3	5.772	5.772	5.774	5.771	5.766	5.763
	4	7.059	7.058	7.053	7.048	7.055	7.048
	5	4.996	4.993	4.992	4.988	4.990	4.987
	Averaged	5.1464	5.1432	5.143	5.1402	5.1406	5.1374

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

Types Of Specimen \ Measured Time		Unit weight at different time (kg/m^3) 3 min	5 min	10 min	15 min	30 min	24 hr
Natural material with 1/2" dense grade	1	2220	2222	2222	2225	2222	2223
	2	2220	2221	2221	2220	2221	2219
	3	2286	2287	2287	2287	2288	2287
	4	2194	2193	2193	2198	2195	2195
	5	2245	2246	2246	2246	2248	2248
	Averaged	2233	2233.8	2233.8	2235.2	2234.8	2234.4
Natural material with 3/4" dense grade	1	2222	2225	2221	2225	2222	2223
	2	2277	2280	2276	2277	2280	2279
	3	2267	2268	2270	2268	2268	2269
	4	2258	2258	2259	2261	2262	2259
	5	2383	2384	2383	2382	2382	2381
	Averaged	2281.4	2283	2281.8	2282.6	2282.8	2282.2
BOF slag with 1/2" dense grade	1	2745	2746	2746	2746	2747	2749
	2	2759	2763	2761	2761	2762	2761
	3	2842	2842	2841	2843	2845	2846
	4	2641	2642	2644	2646	2643	2646
	5	2893	2895	2895	2897	2897	2898
	Averaged	2776	2777.6	2777.4	2778.6	2778.8	2780

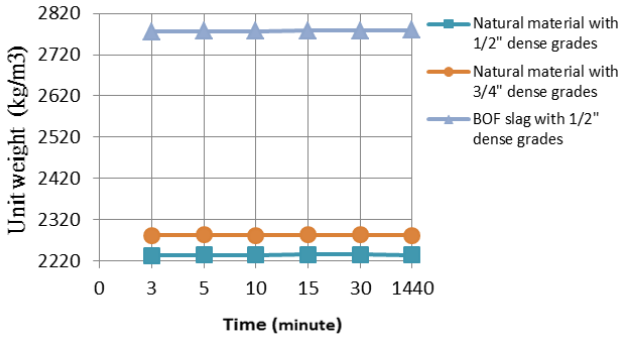

Figure 8 Effect of submerged time on the averaged unit weight measurements for drilled specimens made of three different mixtures using SSDWM under different compaction blows

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. saturated-surface-dry weight method (SSDWM), which is currently the most popular experimental method in practical applications. Some concluding remarks can be itemized as follows:

1. The influence of time of specimen submerged in water on thickness and unit weight is negligibly small in the SSDWM. Thus, in practical operations it seems no need to use too longer time.
2. The higher the number of impact the higher the measured unit weights obtained for all the Marshall specimen using different mixtures..
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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