PREPRINT - NOT FOR PUBLICATION

COMPACTION CHARACTERISTICS OF MICROSURFACES AND SLURRY SEALS BY TRAFFIC SIMULATION WITH THE LOADED WHEEL AND WHEEL TRACKING TESTS

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PREPARED FOR PRESENTATION AT THE INTERNATIONAL SLURRY SURFACING ASSOCIATION 3RD WORLD CONGRESS AND 30TH ANNUAL CONVENTION HELD AT TENERIFE, CANARY ISLANDS, SPAIN
FEBRUARY 23-27, 1992

PART I:	Relationship of uncompacted and compacted voids, aggregate quality and bitumen quality and quantity to unconfined, multilayer lateral and vertical displacement.
PART II:	Effect of Wheel Load and cycles run on ambient LWT rate of compaction using 6 variables.
PART III:	Initial experiments on LWT and WTT correlation and effect of temperature using the Triple-Track Wheel Tracking Machine.

ABSTRACT

The distinguishing difference between slurry seal and polymer modified microsurface is in their comparative resistance to compaction or vertical and lateral displacement by heavy traffic. This property is of critical importance to ensure that multilayers placed in wheel ruts will not re-rut and that a safe macrotexture is maintained under heavy traffic loadings. The prediction of the "overfilling" required to compensate for initial traffic compaction is also important operationally.

The comparative resistance to compaction is measured in the laboratory by the traffic simulation devices; namely the Loaded Wheel Tester (LWT) or the new Triple-Track Modified British Wheel Tracking Tester (WTT). These machines, depending upon conditions, accelerate the effects of traffic.

This paper, in three parts, explores the effects of some 16 variables, including temperature on the compaction characteristics of both Slurry Seal and Polymer Modified Microsurface (Microasphalt or Cold MAC). It was found that each variable measurably affected both the amount and rate of compaction. The most important variables were (1) temperature, (2) Polymer presence and (3) aggregate gradation. At both ambient and high temperature (21°C and 45°C), Polymer presence reduced the amount of compaction by a factor of 2 as were the steady-state rates of compaction at about .10 or less mm/1000 cycles <u>regardless of polymer type</u> under the accelerated test conditions.

In all cases, it was observed that there is a high initial compaction rate until a steady-state rate of compaction is achieved. These rates are dependent upon the amount of wheel loading and temperature. The number of cycles required to reach the steady-state rate as well as the steady-state rate of compaction under the test conditions is considered an important measure of resistance to displacement by traffic.

Between the two test methods (LWT and WTT), the Wheel Tracking Test is preferred because of precision, ease of operation and productivity.

Future work is planned to investigate the major variables of temperature, aggregate gradation and Polymer type and concentration and laboratory correlation with field results.

INTRODUCTION

Early development of the LWT (Loaded Wheel Tester) in 1974 and reported in 1975 at Las Vegas (1) was our first attempt to simulate the effects of traffic in order to predict field performance. The methods developed were reported here at our first World Congress in Madrid, 1977 and published as ISSA Technical Bulletin 109 in 1978 and incorporated as a part of the Technical Bulletin 111, Slurry Seal Design Method (2). At that time, polymer modified slurries were being developed in Spain (3), France (4) and Germany (5)as rutfilling/surface corrective, resurfacing materials where the demands of heavy Autobahn and Motorway traffic required materials which would allow quick traffic, were quite stable and resisted compaction or displacement by the heavy traffic loading.

In 1985, we discovered that the LWT could be used to determine resistance to traffic compaction (6). The LWT would produce data for optimum bitumen contents similar to the Marshall tests but, using a more realistic, dynamic or traffic simulating compaction method.

Since 1985, we have worked with an ongoing program of research to study compaction effects of traffic simulation and have reported the results of our progress each year since then. It is encouraging that the FHWA and Georgia DOT have adapted our methods to hot mixed asphalt concrete for the determination of a variation of rutting potential. Georgia DOT now uses our modified LWT as their standard final hot mix design tool (7). The U.S. Federal Highway Administration in 1990 instituted verification studies in Florida, Kentucky, Wisconsin, Maryland and Utah as well as at the Asphalt Institute's new research headquarters at Lexington, Kentucky. One major U.S. aggregate producer has incorporated the Georgia methods into his new research and customer service laboratory. Additionally, the FHWA Laboratories at Turner-Fairbanks and Denver have recently installed this equipment. A Round Robin study just completed, reported inter-laboratory reproducibility of within 10%! (8).

Work accomplished thus far is outlined as follows:

1. 1974-75 Original LWT work. Physical Appearance and Texture
    - a.) Observed effects of bitumen content or physical appearance and texture depth, smoothness.
    - b.) Excess surface bitumen determined by sand adhesion and
    - c.) Tackiness points.
    - d.) Compaction curves as a function of % bitumen.

2. 1977 Field Tests
   - a.) 1974 A-B Road Test Project (25,000,000 accumulated traffic) relates surface friction numbers to traffic counts. (ISSA 1st World Congress, Madrid-1977).
   - b.) First use of LWT in Mix Design for a DOT project. (Ohio SR 42) Friction numbers related to aggregate size, spread rate, layer thickness, bitumen content and traffic counts.
   - c.) Second LWT design (ODOT SR 64) directly relate friction numbers to traffic counts.

3. 1982 High voids and high permeability discovered in certain polymer modified mixes by Herriman.

4. 1983 ODOT SR 33 "Disaster" clearly related bitumen content, traffic counts, temperature and softening point to rate of decay of friction numbers. Reported in Maui, 1984.

5. 1985 LWT Displacement related to percent bitumen and layer thickness. Inverse Marshall Curves found.

6. 1986 Compaction rate discussed.

7. 1987 Prediction of amount to over-fill ruts to allow for traffic compaction. Classification of multi-layer vertical displacement curves developed into 6 classes. (ISSA 2nd World Congress, Geneva).

8. 1988 3 different systems analyzed and compared for ambient LWT and high temperature Wheel Tracking Test, vertical and lateral displacement. Best Marshall tests are worst hi-temp Wheel Tracking Tests.

9. 1989 Effects of gradation and voids on LWT displacement examined. Coarser gradations, with lower voids, do better.

   Differences noted between Slurry and Microasphalt LWT displacement behavior. Very high field or traffic compacted voids found by Ballou and others.

10. 1990
   - a.) Density-specific gravity of compacted and uncompacted slurry related to percent displacement.
   - b.) Total liquids and mix density related.
   - c.) Laser measurement of compaction rates reported.
   - d.) Optimization of the entire system including rates of compaction.

The Part I and Part II of this paper reports on some of the work accomplished in our 1989 and 1990 research program as well as our plans for 1991 research work and includes:

PART I Relationship of uncompacted and compacted voids to vertical and lateral unconfined LWT displacement as affected by percent bitumen content, and quality of mix components.

PART II Effect of wheel load and run time on ambient LWT rate of compaction with 6 variables including:
a.) Unmodified, generic slurry and performance slurry.
b.) 0/#4 and 0-5/16" (0/5, 0/8)aggregate gradations.
c.) Filler contents.
d.) Different polymer systems.
e.) Effect of pH.
f.) 3 emulsifier types.
g.) Wheel applied loads of 75 @ 125 pounds.
h.) Cycles run: 1000, 2000, 3000, 4000, 8000.

Rate of compaction which we consider a very important characteristic of cold microasphalt was first studied by manual Profilograph in 1974. At ISSA's 1990 Tampa meeting, we suggested measurement of compaction rates by laser, which, while it works, our system suffered some disadvantages because of the time required for data retrieval and expense.

<u>PART 1</u> RELATIONSHIP OF UNCOMPACTED AND COMPACTED VOIDS TO LWT DISPLACEMENT AND SPECIFIC GRAVITY

We have previously shown ( ) that our original suggested performance limits of 10% vertical and 5% lateral multilayer displacement did not account for compacted voids; i.e., the percent compaction could be much greater (as much as 25-30%) and still have compacted voids or related specific gravity of about 10-12% and 2.10 respectively depending upon the initial specific gravity of the uncompacted, as-cast specimen. Uncompacted voids can vary widely and affect percent compaction values. Compacted specific gravity/voids may be a better measure of real world compaction, especially with microsurfaces.

The following 4 examples (figures 1,2,3,4) show the effects of a high quality, unmodified emulsion with high quality aggregates which have low and high fines contents, and a poor quality high fines aggregate mixed with good and poor unmodified emulsions.

All four emulsions were made with same high quality emulsifier, the difference in emulsion quality is due to the base asphalt quality in this example.

The good quality systems here clearly show "optimum" resistance to compaction at 12% AE for low voids and 18% for high voids. The poor quality aggregate with low voids required 16% good quality emulsion and 18% AE with poor quality emulsion.

The unusual new feature in this set of curves is the convergence of the umcompacted and compacted specific gravity at the maximum resistance to displacement (percent vertical and lateral displacement) and a divergence with further increase in emulsion content. Here total mix liquids play a small role while the heavier sample weights seems to correlate better.

The apparent very wide range of emulsion contents requirement for maximum resistance to loaded wheel displacement bears further investigation. What is clear is that aggregate quality and bitumen quality as well as the voids or "space for bitumen" or gradation are important factors which deserve more study.

PART 2 EFFECT OF WHEEL LOAD AND RUN TIME ON AMBIENT (20-21°C) LWT RATE OF DISPLACEMENT

Figure 1 shows two identical LWT mixes prepared by different technicians. While their uncompacted specific gravities were initially 1.82 and 1.88, their specific gravities approached each other at 2.10 and 2.11 after 1000, 125 lb. LWT cycles. At 3000 more cycles each sample had identical compacted specific gravities of 2.24. This finding led us to experiment with the compaction behaviors at 4000 and up to 8000 cycles on several samples and to observe the effects of more compaction effort.

Figure 2 compares Anionic and Cationic SBR coemulsified latex mixes at 4000 cycles. There is a high initial rate of compaction which levels off after 1000, 125-lb. ambient LWT cycles into a steady rate of displacement. the curves are practically identical or parallel with the anionic latex resisting compaction at a slightly lower level but at the same rate.

Figure 3 compares a polymer "A" modified system at .5 and 1.0% cement. Each show a high initial rate of displacement. At .5% pc this high rate is continued while at 1% pc the rate makes a much slower turn and continues the lower rate for at least 4000 cycles. This is a pattern which becomes quite familiar in future tests.

Figure 4 shows the effect of gradation and cement content on a natural latex emulsion. The 0/#4 gradation has a very high initial compaction but stabilizes at steady rate at 1000 cycles while the 0-5/16" does not stabilize until 3000 cycles and then at a lower rate or slope.

Figure 5 This natural latex system shows the effect of emulsifier pH and filler contents. The low pH, in this case, had comparatively high rates or displacement slopes while the high pH displacement rate was lower. Note the much lower compaction rate at high pH and high cement.

Figure 6 Yet another SBR system shows 11% AE compacting at a constant rate without pause while the 12% AE rate slows considerably after 1000 cycles. Of special interest is one specimen which recovered 30% of its original compaction upon standing for 7 days. (elastic recovery?, error?)

Figure 7 After observing this "elastic recovery" we found the same thing happening with a natural latex specimen which we discovered had recovered 11.5% of its compacted track depth. After 4000 (8,000 total), additional 125 lb. LWT cycles the slope or rate of compaction had become practically flat, thus adding a whole new dimension to our researches; that of elastic recovery, cycle rate or rest periods to allow more time for recovery between load applications.

The actual load on our wheel varied from 157 to 130.5 lbs. depending upon the crank position and bears on a contact area of about .8in^2. We estimate these loads to approach 4 times the contact pressure of a loaded truck tire. By reducing our applied load from 125 to 75 lbs. the contact area is slightly reduced and the actual wheel load is from 117 to 90.0 lbs. or a reduction in average load from 143.5 to 103.5 lbs.; about 2½ times truck tire contact pressure.

Figure 8 A polymer "A" system compares the difference between the 125 and 75 lb. applied loads. What we see with 125 lb. load is a constant rate of compaction after 4000 cycles or a track depth rate of .08mm/1000 cycles or .20 mm per hour.

With applied load reduced to 75 lbs., a constant rate of compaction after 2000 cycles or track depth rate of the **identical** .08mm/1000 cycles or .20 mm per hour, though at a much lower level.

It's noted that a steady-state rate of compaction at a 125 lb. load was not achieved until 4000 cycles while at 75 lb., the steady-state rate was achieved at 1000-3000 cycles, AT 25-75% LESS COMPACTION EFFORT than the heavier load.

Figure 9 Compares 75 lb. applied load at ambient compaction or displacement characteristics of 3 different polymer systems with an unmodified plain system. All samples used the identical mix formula of 0-5/16" gradation, 1% pc and 11% emulsion. Polymer use level was 3% on the pure bitumen.

The tabular results are:

	PLAIN	SBR	NATURAL	A5
1. Vertical Displacement, %	34	14	15	9
2. Lateral Displacement, %	18	3	2.5	2
3. Cycles to Steady Rate of Specific Gravity Increase	8000+	3000	2000	2000
4. Initial Specific Gravity	1.82	1.92	1.79	1.96
5. Specific Gravity at Beginning of Steady Rate Increase*	2.43+	2.11	1.92	2.09
6. Specific Gravity @ 8000 Cycles	2.43	2.18	2.06	2.15
7. Specific Gravity Rise at 8000	.61	.21	.27	.19
8. Steady Rate of Specific Gravity Increase/K cycles	.043	.015	.015	.011
9. Cycles to Steady-State Rut Rate or Track Depth	8000+	3000	2000	1000
10. Steady Rut/Track Rate, mm/k	.28	.09	.11	.08
11. Elastic Recovery, 7 Days (?) mm	.22	.17	.33?	.16

*ASG = 2.77

TABLE 1. EFFECT OF POLYMER ADDITION ON COMPACTION RATES (figure 9)

COMMENTS ON PARTS I AND II

We caution again, that **EACH SYSTEM IS ITS OWN THING.** As amply illustrated in these examples, small changes in gradation, cement or additive content, emulsion content, emulsifier concentration, pH and polymer type can dramatically affect the shape of these curves. Each system should be optimized for best performance.

All curves show a high initial compaction rate which continues until the compaction force is balanced by the mix resistance to this compaction force; i.e., an equilibrium is reached. These forces are balanced at a various number of cycles or total compaction effort. The compaction rate then levels off into a smooth low slope curve characteristic of the particular material combination. It appears that the rate of steady state compaction **IS ESSENTIALLY THE SAME FOR ALL POLYMERS TESTED.** The differences lie in the **AMOUNT** of compaction required to reach a steady-state rate of compaction.

The elastic recovery phenomena is new to us but should be studied, particularly the rate of rebound in relation to wheel load frequency and time for "relaxation" as well as the effects of temperature.

Previous work has identified 6 classes of compaction behavior due to polymer presence and layer thickness but at only 1000, 125-lb. LWT cycles. The work in Part 2 of this paper extended the cycles to 4000 and 8000 as well as reduced LWT wheel loads.

LWT cycles at ambient in most cases, may be predictive of comparative compaction at additional cycles. 1000 cycles alone should probably not be used for this purpose.