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COMPACTION BEHAVIOR CHARACTERISTICS OF MICROASPHALTS AND SLURRY SEALS BY TRAFFIC SIMULATION WITH THE LOADED WHEEL AND WHEEL TRACKING TESTS - A PROGRESS REPORT

By C. Robert Benedict, Consultant
C/O Alpha Labs
P.O. Box 74, Alpha, OH 45301
513-298-6647 FAX: 513-426-3368

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INTRODUCTION

Early development of the LWT in 1974 and reported in 1975 at Las Vegas was our first attempt to simulate the effects of traffic. Methods developed were published as ISSA Technical Bulletin 109 in 1978 and incorporated as a part of the Technical Bulletin 111, Slurry Seal Design Method. At that time, polymer modified slurries were being developed in Spain, France and Germany as rut filling/correction-resurfacing materials where the demands of heavy Autobahn and Motorway traffic required materials which 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. 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 our 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 rutting potential. Georgia DOT now uses our modified LWT as their standard final hot mix design tool. Recently, the Federal Highway Administration has this past year 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 aggregate producer has incorporated our methods in his new research and customer service laboratory.

Our work 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 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.
   - 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 discovered.

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.

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 gradation, 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 following reports on some of the work accomplished this past year as well as our program for 1991 and includes:

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

2. 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" 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.

3. Initial runs on new 3-track, air-loaded modified British Wheel Tracking Test Machine.
   - a.) Test set-up. Environmental chamber, temperature control and recording instrumentation, computer program, printer and plotter.
   - b.) Load-weight calibration.
   - c.) Program:
     3-temps @ 70, 105, 115F (21,40,45C)
     3-loads @ 63.8 lbs/in (29kg.) (11.2 N/mm)

Rate of compaction which we consider a very important characteristic of cold microasphalt was first studied by manual Profilograph in 1974. At last year's 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.

PART 1 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.

The following 4 examples 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.

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 roll 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 LWT <u>RATE</u> 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 lead 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?)

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 is 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 rate of compaction at a 125 lb. load was not achieved until 4000 cycles while at 75 lb. the steady rate was achieved at 2000 cycles AT 50% LESS COMPACTION 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.

The tabular results are:

	PLAIN	SBR	NATURAL	A 5
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 Rut Rate or Track Depth	8000+	2000	2000	2000
10. Steady Rut/Track Rate, mm/k	.28	.09	.11	.08
11. Elastic Recovery, 7 Days (?) mm	.22	.17	.33	.16

* ASG = 2.77

All samples used the identical mix formula of 0-5/16" gradation, 1% pc and 11% emulsion. Polymer use level was 3% of pure bitumen.

We caution again, that **EACH SYSTEM IS ITS OWN THING.** As amply illustrated in the earlier examples, small changes in cement or additive content, emulsion content, emulsifier concentration and pH 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. 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 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.

PART 3 COMPACTION CHARACTERISTICS OF MULTILAYERED MICROASPHALTS AT ELEVATED TEMPERATURE MEASURED BY OUR NEW 3-TRACK AIR-LOADED, BRITISH WHEEL TRACKING TEST.

Our WTT testing program has only just begun consequently there is not enough meaningful data to report here.

The WTT machine avoids the disadvantage of a variable LWT wheel load due to the rocking motion of the LWT since the WTT wheel is stationery and the specimen moves horizontally on a reciprocating specimen mounting plate.

The load is easily applied through individually regulated air pressure in the air cylinders. The wheels can be easily lifted by air for sample mounting. The load can also be programmed for undirectional compaction or for cycle frequency of applied load.

Provision is made for rut depth measurement in motion by LVDT as well as for manual dial gauge measurements for calibration and confirmation.

The measure-in-motion feature may be programmed for any specimen segment and for time lapse or cycle period. Data is read out digitally and printed out on a tape. Data from each cycle is computer stored, averaged and plotted directly on a laser printer.

We hope also to measure macrotexture depth in motion by aggregate penetration into the rubber tire by difference in loaded and unloaded contact. Also we hopefully will be able to pick up elastic rebound or recovery by similar technique.

The entire apparatus is placed in a environmental chamber where temperatures may be closely controlled and varied from 20 to 60°C (70-140°F).

In previous work with our wheel tracking machine, we've reported virtually no difference in displacements at 70F and 115F for certain polymer systems. We also found in our initial experiments with plain, unmodified systems that the best Marshall stabilities yield the worst high temperature wheel tracking rates. We hope to verify these initial findings.

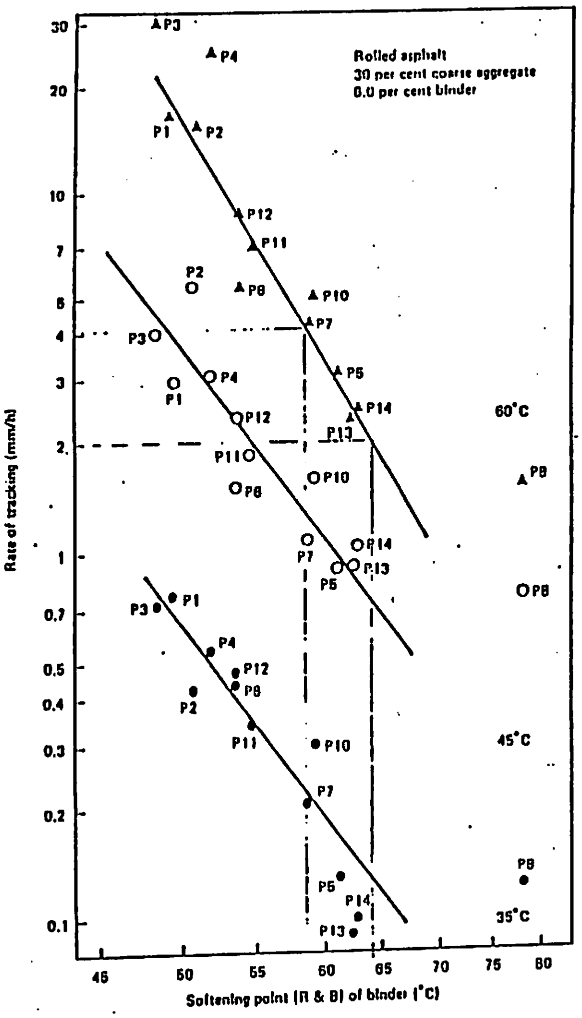
Among the variables we hope to investigate are:

1. Wheel Load
2. Temperature
3. Emulsifier Type, %, pH
4. Bitumen Type
5. Polymer Type
6. Filler Type and Quantity
7. Additive Type and Quantity
8. Aggregate Shape - Particle Interlock
9. Odd Gradations
10. Voids in Mineral Aggregate
11. Voids Filled with Bitumen

Duplicate Multilayer specimens of the LWT mixes reported in this paper as well as the SHRP specimens have been retained and will be run at the best run conditions which we will determine by examining a number of running conditions.

THE BRITISH WHEEL TRACKING EXPERIENCE

At TRRL, considerable work on the Wheel Tracking Simulator has been accomplished in regards to Hot Mix AC or "Hot Rolled Asphalts". Wheel Tracking Rates for satisfactory rates of rutting in relation to commercial vehicles per day have been established (2 mm per hour at 45C for 6000 trucks per day). Figure 10, the relationship between the rutting rate and Ring & Ball Softening Point, is an example of how we may take advantage of work already accomplished for us at TRRL.



Effect of softening point of binder on rate of tracking at 35, 45 and 60°C

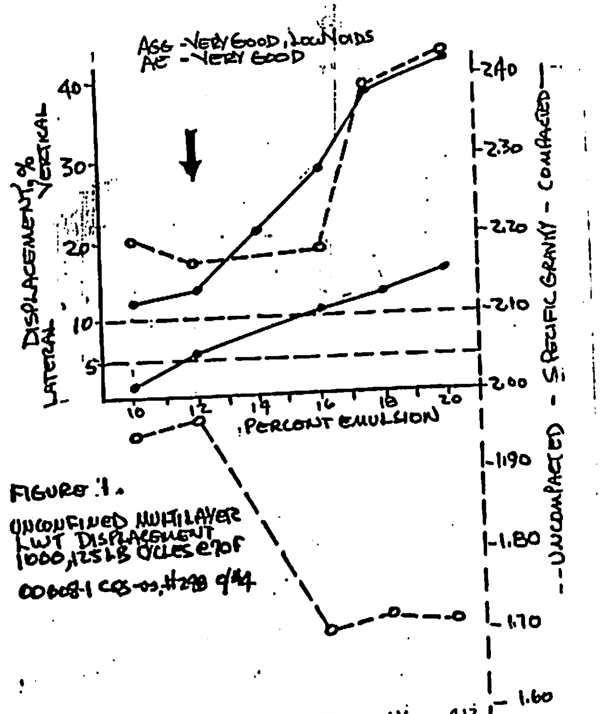


FIGURE 1.

UNCONFINED MULTILAYER
LWT DISPLACEMENT
1000, 125LB CYCLES @ 70F

00608-1 CRS-03, #298 9/84

NET WEIGHT	416	459	446	410	416	412
TOTAL LIQUIDS	22	22	–	23	24	24
Δℓ, MM	63	50	–	124	171	182
Δ sg.	.28	.25	–	.41	.49	.79

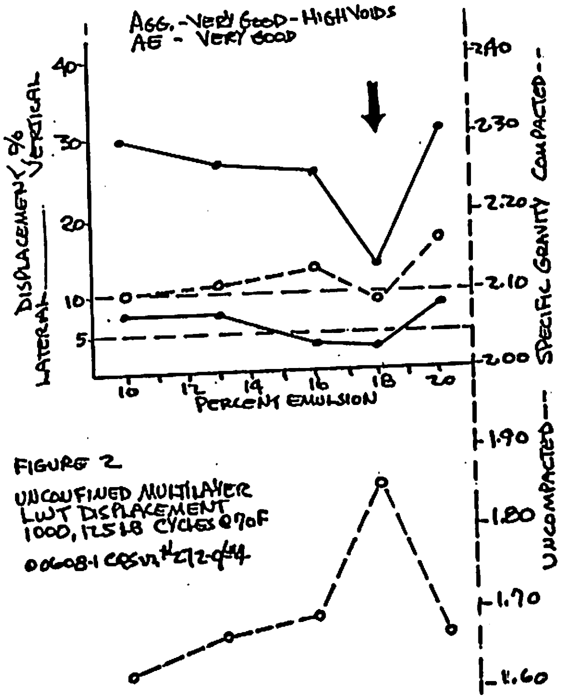


FIGURE 2

UNCONFINED MULTILAYER
LWT DISPLACEMENT
1000, 125LB CYCLES @ 70F

00608-1 CRS-VI #272-9/84

Δℓ	121	111	111	61	126
Δ sg	.48	.44	.44	.24	.50

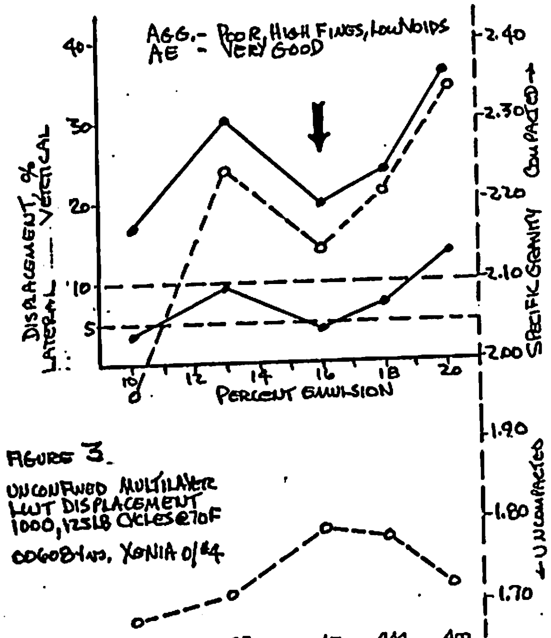


FIGURE 3.

UNCONFINED MULTILAYER
LWT DISPLACEMENT
1000, 125LB CYCLES @ 70F

00608-1 WS, XENIA 0/84

NET WEIGHT	413	397	452	444	402
TOTAL LIQUIDS	27	28	29	29	29
Δℓ mm	69	132	88	108	157
Δ sg.	.28	.53	.35	.45	.62

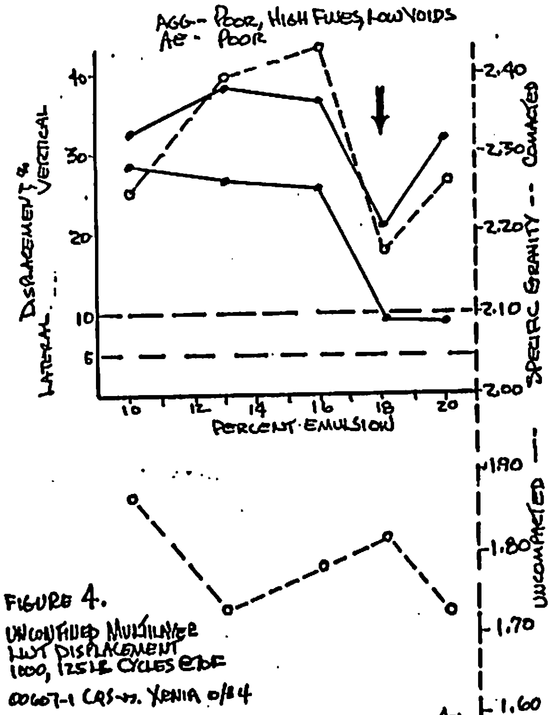


FIGURE 4.

UNCONFINED MULTILAYER
LWT DISPLACEMENT
1000, 125LB CYCLES @ 70F

00607-1 CRS-WS. XENIA 0/84

Net Weight	446	406	408	–	421
TOTAL LIQUIDS	24	26	26.5	–	28
Δℓ mm	96	167	163	90	135
Δ sg	.37	.66	.65	.36	.54

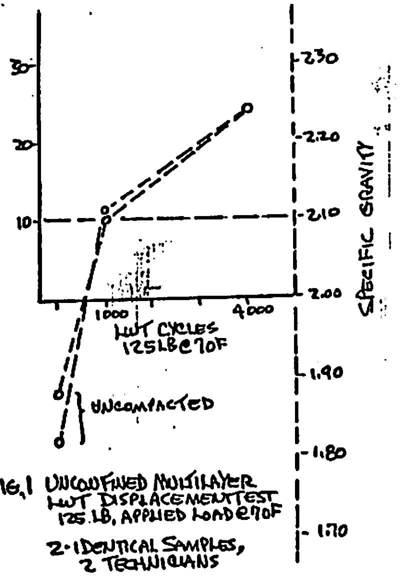


FIG. 1 UNCONFINED MULTILAYER HWT DISPLACEMENT TEST 125.LB, APPLIED LOAD @70F

2-IDENTICAL SAMPLES, 2 TECHNICIANS

#001128-1-W.#298 0/#4
.5pc-7-12

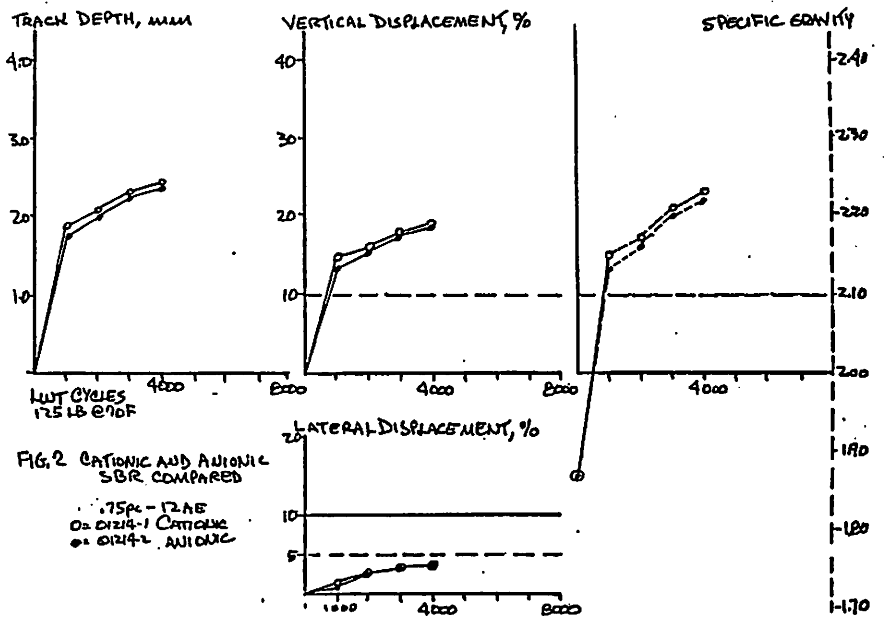


FIG. 2 CATIONIC AND ANIONIC SBR COMPARED

.75pc - 12AE
O= 01214-1 CATIONIC
●= 01214-2 ANIONIC

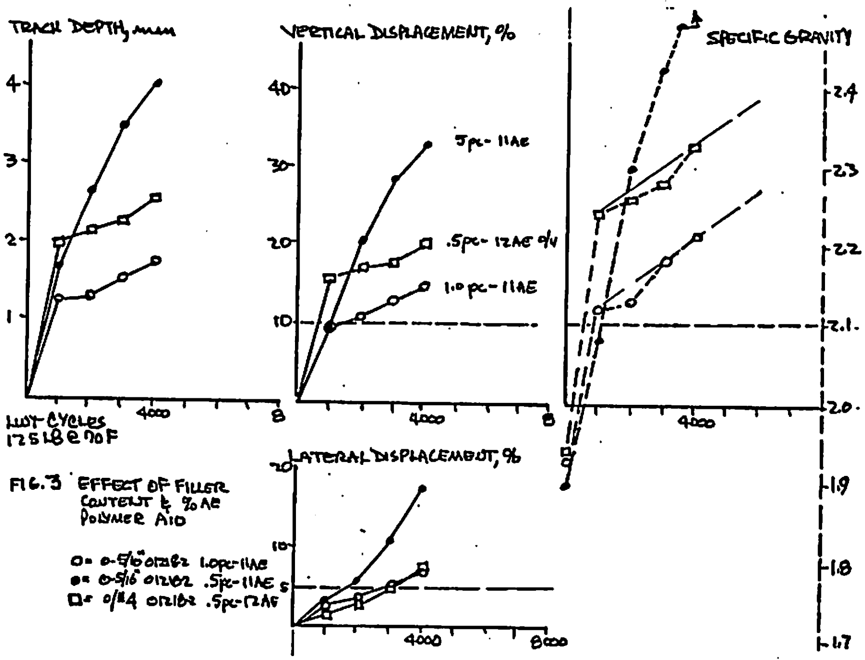


FIG. 3 EFFECT OF FILLER CONTENT & %AE POLYMER AID

O= 0-5/16" 012182 1.0pc-11AE
●= 0-5/16" 012182 .5pc-11AE
□= 0/#4 012182 .5pc-12AE

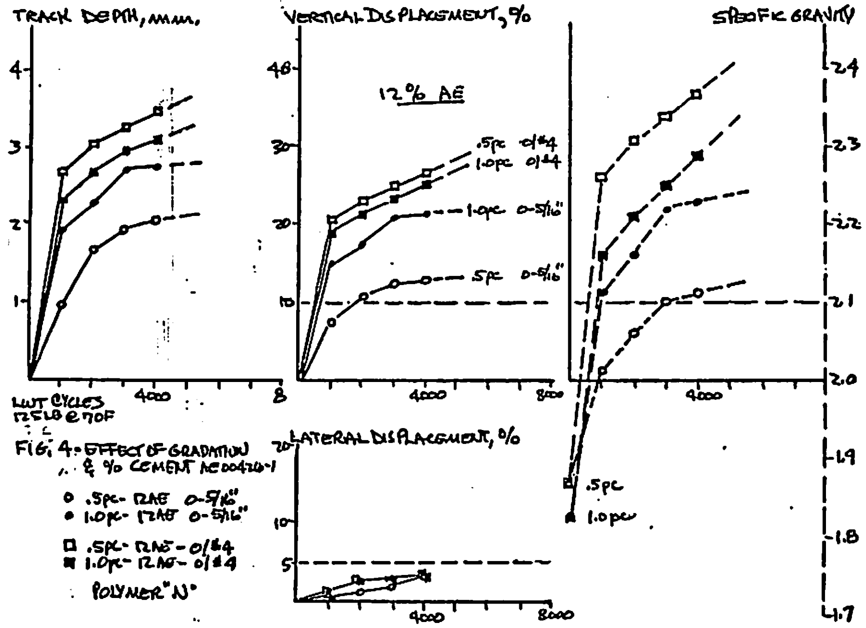


FIG. 4 - EFFECT OF GRADATION & % CEMENT AE00420-1

- ○ .5pc - 12AE 0-5/16"
- ● 1.0pc - 12AE 0-5/16"
- □ .5pc - 12AE - 0/#4
- ■ 1.0pc - 12AE - 0/#4

POLYMER "N"

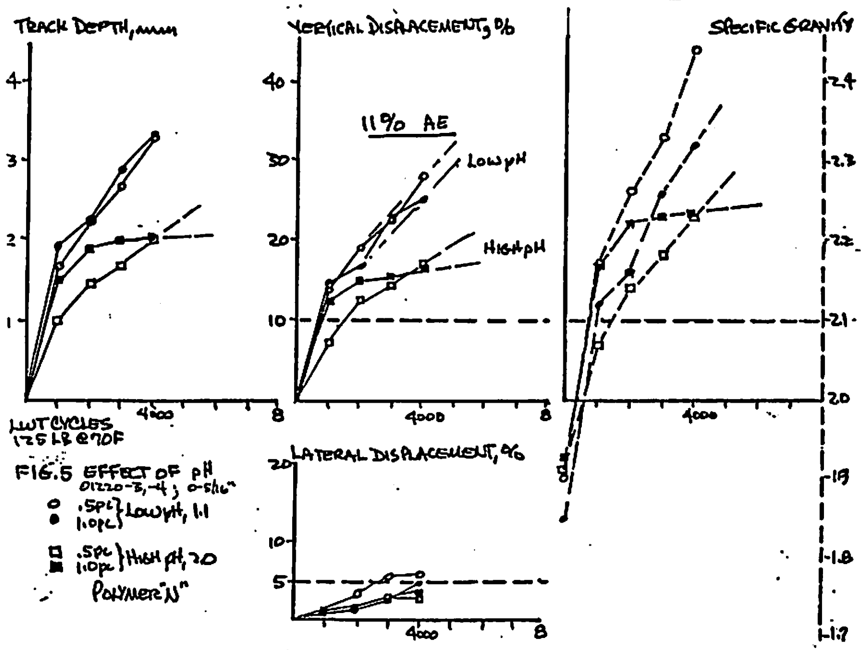


FIG. 5 EFFECT OF pH
01220-3, -4; 0-5/16"

- ○ .5pc } Low pH, 1.1
- ● 1.0pc } Low pH, 1.1
- □ .5pc } HIGH pH, 2.0
- ■ 1.0pc } HIGH pH, 2.0

POLYMER "N"

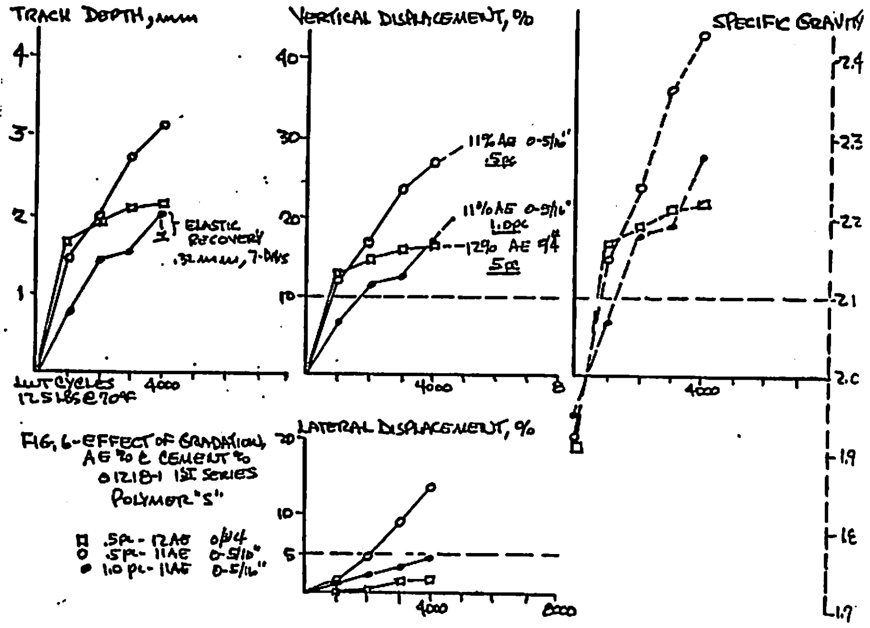


FIG. 6 - EFFECT OF GRADATION, AE % & CEMENT %
01218-1 1ST SERIES
POLYMER "S"

- □ .5pc - 12AE 0/#4
- ○ .5pc - 11AE 0-5/16"
- ● 1.0 pc - 11AE 0-5/16"

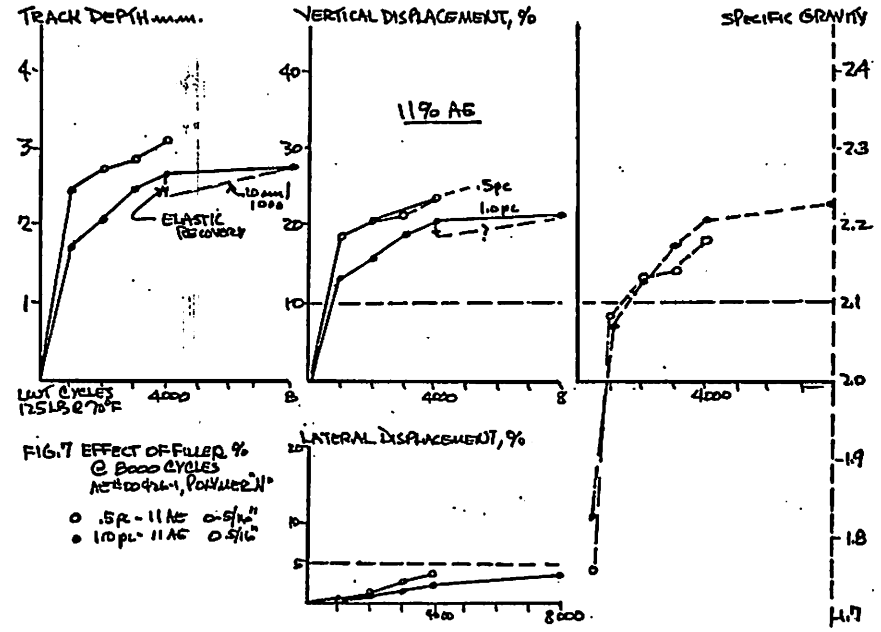


FIG. 7 EFFECT OF FILLER % @ 8000 CYCLES AC #00926-1, POLYMER "U"

○ .5pc - 11 AE 0-5/16"
● 1.0pc - 11 AE 0-5/16"

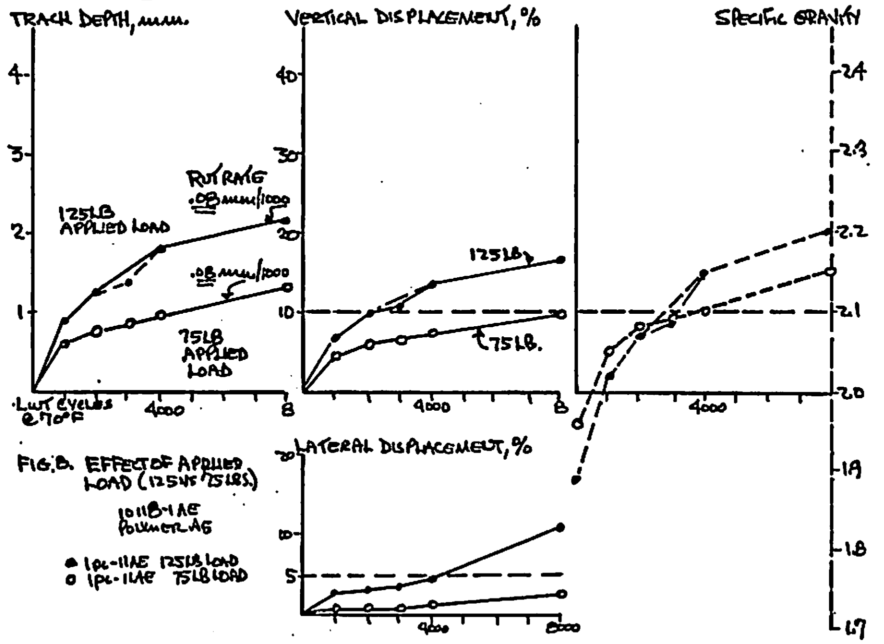


FIG. 8. EFFECT OF APPLIED LOAD (125 vs 75 LBS.)

10118-1 AE
POLYMER AS

● 1pc-11AE 125LB LOAD
○ 1pc-11AE 75LB LOAD

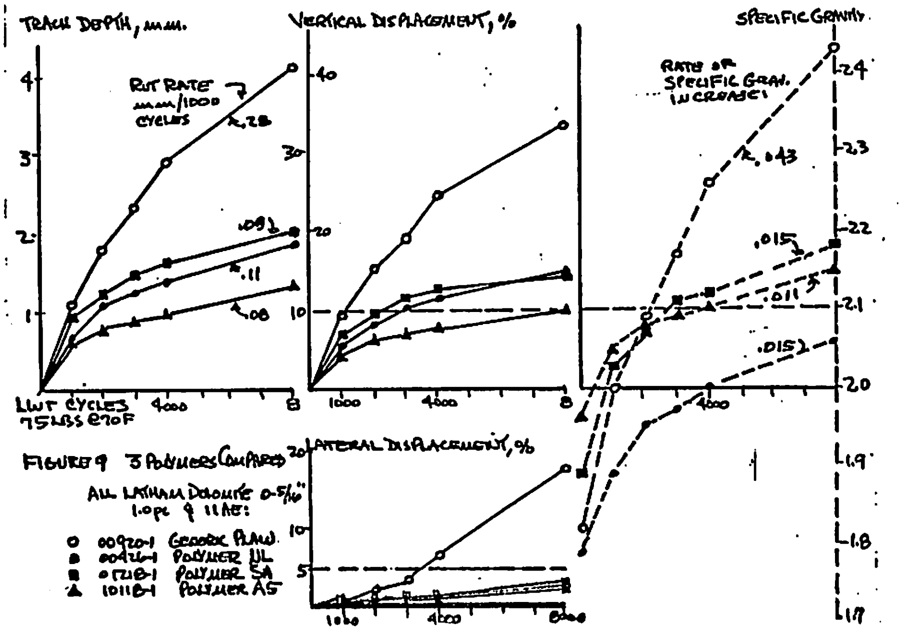


FIGURE 9 3 POLYMERS COMPARED

ALL LATHAM DOLOMITE 0-5/16"
1.0pc @ 11AE:

○ 00920-1 GEOROX PLAIN.
● 00926-1 POLYMER UL
■ 01218-1 POLYMER SA
▲ 10118-1 POLYMER AS