July 13, 2007

Mr. Michael Voth, P.E.
Functional Pavements Discipline Leader
Central Federal Lands Highway Division
12300 West Dakota Avenue
Lakewood, CO 80228

Dear Mr. Voth: Re: CA PGH 123-1(1), Washington Road

The cold in-place recycled (CIR) mix designs for project number CA PGH 123-1(1), Washington Road, has been completed. Sufficient millings were not supplied to complete all testing requested and, due to high relative humidity levels in our laboratory, the raveling tests could not be completed. The mix design was performed in general accordance with the CIR mix design methods and procedures specified by the Kansas Department of Transportation and the requirements of the CFLHD. The test procedures followed are shown in table 1.

The mix design was completed on pieces of pavement and aggregate base provided by CFLHD that were obtained from three stations or test pits from the above referenced project. Table 2 shows the sample locations and the percent aggregate base to be blended with the RAP at each test pit. The materials from each test pit were evaluated with three different recycling agents, Reflex emulsion, HFMS-2P emulsion and HFMS-2P emulsion with one percent hydrated lime added as 3.3% slaked lime slurry. All percents are based on the dry mass of the RAP. The Reflex emulsion was provided by SemMaterials and the HFMS-2P was provided by Albina Asphalt.

Sample Preparation
For each test pit, the aggregate base was split to the required testing size in accordance with AASHTO T 248. The aggregate base was then oven dried to a constant mass at 230°F. The materials were separated by size on the 1.5 inch to No. 8 sieve, inclusive, and the mass determined. A 2,000g sample of the material passing the No. 8 sieve was obtained and a washed sieve analysis was performed in accordance with AASHTO T 11 and T 27. The combined sieve analysis was determined by mathematically combining the two gradations. The results are shown in table 3.

For each test pit, the RAP was frozen and then reduced to minus 1.5 inch in size by crushing in a jaw crusher. After crushing, the RAP was died to a constant mass at 104°F and separated by size on the 1.5 inch to No. 8 sieve, inclusive, and the mass determined. A 2,000g sample of the material passing the No. 8 sieve was obtained and a sieve

analysis was performed in accordance with AASHTO T 27. The gradation of the RAP was determined by mathematically combining the two gradations.

It is not possible to crush RAP so that the combined gradation of RAP plus aggregate would match the blended gradation requirements of the CFLHD. To meet the blended gradation requirements, the as received gradation of the aggregate base was held constant and the required gradation of the RAP calculated so that the blend would meet the CFLHD requirements. The gradation of the RAP was adjusted within the gradation limits to optimize use of the RAP. The gradation of the RAP used and the blended gradation, along with the CFLHD requirements, are shown in table 3.

Test Results

Summary results from the testing are shown in table 4. Plots of the test results with emulsion contents are shown in figures 1-3 for each recycling additive, respectively. The curing conditions for the raveling test (ASTM D 7196) are not specified. Two common curing procedures are ambient conditions and 10°C at 50% relative humidity. Tests at ambient conditions (70°F, 68% relative humidity) were performed on samples prepared at optimum emulsion content from test pit 3. Due to the high relative humidity and cool temperatures in our laboratory, little curing of the samples appeared to have occurred and all samples failed the test in less than five minutes. Samples were made at optimum emulsion content with Reflex only for test pits 1 and 2 with the same failing results. We were unable to perform the raveling test at 10°C and 50% relative humidity as our environmental chamber could not maintain 50% relative humidity at 10°C with the current high ambient relative humidity levels of our laboratory. Testing was discontinued to conserve materials.

Analysis of Results

There are no universal specification requirements for CIR mix designs. Commonly used specifications are a minimum Marshall stability of 1200 to 1250 lbs. at 40°C and a retained Marshall stability ratio of 0.70. AASHTO T 283 is occasionally performed on CIR samples, although the procedure is difficult to perform. Difficulties are encountered due to the presence of uncoated aggregate and the high void contents typically found in CIR mixtures. Modifications to the initial sample curing procedures are generally required and the sample conditioning temperatures are often decreased. Sufficient RAP was not available to complete the requested AASHTO T 283 testing.

The HFMS-2P was not able to meet typical specification requirements for any of the three test pits. For test pits 1 and 2 with aggregate base, the HFMS-2P did not coat and adhere to the base rock. This poor coating and adhesion manifest itself in low retained stability ratios. HFMS-2 is an anionic emulsion and the base rock was not calcareous, which could have contributed to the adhesion and coating problems. For test pit 3, the emulsion content required to pass the retained Marshall stability ratio produced dry Marshall stability values below the recommended minimum. I do not recommend using HFMS-2P emulsion without adding hydrated lime.

Using 3.3% lime slurry, which contained a minimum of 1.0% hydrated lime solids, with the HFMS-2P emulsion improved both the dry Marshall stability values and the retained Marshall stability ratio. For test pits 1 and 2, a minimum emulsion content of 2.0% was required to satisfy the typical Marshall stability and retained stability requirements. The typical Marshall stability and retained stability requirements were met with a minimum of 1.5% emulsion for test pit 3.

Reflex is a cationic emulsion and there were no apparent coating or adhesion problems with the base rock. For all three test pits, a minimum emulsion content of 2.0% was required to satisfy the typical Marshall stability and retained stability requirements.

Recommendations

Based on the results of the testing performed and the gradations of the materials evaluated, the recommended minimum optimum asphalt emulsion, lime slurry and mix water contents for RAP and aggregate base, that meets the gradation band shown in table 3, are provided in table 5.

Field adjustments to the minimum emulsified asphalt content and /or mix water content may be required as the test results are representative of results obtained from RAP produced from crushed pavement sections blended with the specified percentages of aggregate base. The gradation of the blended material may not be representative of the actual CIR materials from each test section. RAP and aggregate base were tested in an oven dry condition and field samples will contain some moisture, possibly reducing mix water demand.

This concludes my services for this project. Should you need any additional information please contact me at 405-744-7200 or by e-mail at steve.cross@okstate.edu.

Sincerely,

Stephen A. Cross, Ph.D., P.E.

Enclosures

Table 1. Mix Design Test Procedures

Test Procedures
Superpave gyratory compaction. AASHTO T 312, 35 gyrations, 100 mm mold
Sample curing, KDOT Construction Manual, Part V – Materials, Sec. 5.18.04 (6)
Bulk Specific Gravity, AASHTO T 166
Maximum Specific Gravity, ASTM D 6857
Marshall stability, ASTM D1559, Part 5, 40°C, lbs.
Retained Marshall stability after soaking based on cured stability, %. KDOT Construction Manual, Part V – Materials, Sec. 5.18.04 (8)
Raveling Test, ASTM D 7196, AASHTO T 312 compaction, 30 gyrations, 150 mm mold

Table 2. Sample Information

Test Pit	Station	Lane	% RAP	% Agg. Base
1	85+00	Left	75	25
2	130+00	Right	75	25
3	265+00	Left	100	0

Table 3. Gradation of Materials

Sieve	TP 1			TP 2			TP 3		CFLHD
Size	RAP	Agg.	Blend	RAP	Agg.	Blend	RAP	Blend	Spec
1.5"	100	100	100	100	100	100	100	100	100
1"	98	86	95	100	94	99	98	98	90-100
3/4"	87	78	85	90	88	90	87	87	85-95
1/2"	78	65	75	80	77	79	77	77	75-85
3/8"	54	58	55	55	69	59	57	57	
No. 4	40	42	41	35	49	39	40	40	35-50
No. 8	15	33	20	19	34	23	15	15	
No. 16	9.4	24	13	12	23	15	8.8	8.8	5-15
No. 30	4.7	17	7.8	6.5	15	8.6	4.0	4	
No. 50	2.1	12	4.6	2.7	11	4.8	1.8	1.8	
No. 100	0.8	8.0	2.6	1	8.3	2.8	0.7	0.7	
No. 200	0.3	5.2	1.5	0.3	7.6	2.1	0.2	0.2	0-7.0

Table 4. Summary of Test Results

Sample	Location	EAC	EAC (%)	Lime Slurry (%)	Mix Water (%)	Bulk Specific Gravity	Maximum Specific Gravity	VTM (%)	Dry Stability (lbs)	Vacuum Sat. (%)	Conditioned Stability (lbs)	Retained Stability Ratio	Raving Test
TP 1	Sta 85+00	Reflex	1.5	0.0	5.0	2.063	2.478	16.7	1710	73.1	1040	0.61	
TP 1	Sta 85+00	Reflex	2.0	0.0	4.5	2.062	2.467	16.4	1605	71.9	1145	0.71	Failed
TP 1	Sta 85+00	Reflex	2.5	0.0	4.0	2.065	2.456	15.9	1685	71.0	1325	0.79	
TP 1	Sta 85+00	Reflex	3.0	0.0	3.5	2.057	2.443	15.8	1720	74.0	1530	0.89	
TP 1	Sta 85+00	HFMS-2P	1.5	0.0	5.0	2.085	2.449	14.9	1596	78.0	760	0.48	
TP 1	Sta 85+00	HFMS-2P	2.0	0.0	4.5	2.084	2.437	14.5	1219	74.3	650	0.53	
TP 1	Sta 85+00	HFMS-2P	2.5	0.0	4.0	2.103	2.425	13.3	1082	73.9	815	0.75	
TP 1	Sta 85+00	HFMS-2P	1.5	3.3	1.7	2.086	2.419	13.8	1434	78.8	1099	0.77	
TP 1	Sta 85+00	HFMS-2P	2.0	3.3	1.2	2.091	2.406	13.1	1276	78.5	1020	0.80	
TP 1	Sta 85+00	HFMS-2P	2.5	3.3	0.7	2.095	2.397	12.6	1135	77.1	1010	0.89	
TP 2	Sta 130+00	Reflex	2.0	0.0	4.5	2.039	2.421	15.8	1713	79.4	1245	0.73	Failed
TP 2	Sta 130+00	Reflex	2.5	0.0	4.0	2.030	2.410	15.8	1755	72.6	1230	0.70	
TP 2	Sta 130+00	Reflex	3.0	0.0	3.5	2.052	2.400	14.5	1761	74.8	1300	0.74	
TP 2	Sta 130+00	HFMS-2P	2.0	0.0	4.5	2.093	2.439	14.2	1414	76.9	750	0.53	
TP 2	Sta 130+00	HFMS-2P	2.5	0.0	4.0	2.100	2.428	13.5	1504	75.1	825	0.55	
TP 2	Sta 130+00	HFMS-2P	2.0	3.3	1.2	2.075	2.410	13.9	1421	70.6	995	0.70	
TP 2	Sta 130+00	HFMS-2P	2.5	3.3	0.7	2.085	2.399	13.1	1570	77.3	1160	0.74	
TP 2	Sta 130+00	HFMS-2P	3.0	3.3	0.2	2.067	2.387	13.4	1477	73.8	1170	0.79	
TP 3	Sta 265+00	Reflex	1.5	0.0	3.5	2.007	2.412	16.8	1387	76.7	1235	0.89	
TP 3	Sta 265+00	Reflex	2.0	0.0	3.0	2.013	2.405	16.3	1264	76.3	1250	0.99	Failed
TP 3	Sta 265+00	Reflex	2.5	0.0	2.5	2.018	2.394	15.7	1269	79.8	1140	0.90	
TP 3	Sta 265+00	HFMS-2P	1.5	0.0	3.5	2.049	2.445	16.2	1261	70.6	863	0.68	
TP 3	Sta 265+00	HFMS-2P	2.0	0.0	3.0	2.048	2.435	15.9	1077	71.8	865	0.80	Failed
TP 3	Sta 265+00	HFMS-2P	2.5	0.0	2.5	2.052	2.423	15.3	830	72.7	705	0.85	
TP 3	Sta 265+00	HFMS-2P	1.5	3.3	1.7	2.035	2.417	15.8	1288	79.6	1146	0.89	
TP 3	Sta 265+00	HFMS-2P	2.0	3.3	1.2	2.044	2.408	15.1	1236	72.2	1000	0.81	Failed
TP 3	Sta 265+00	HFMS-2P	2.5	3.3	0.7	2.035	2.394	15.0	1175	71.5	1060	0.90	

Table 5. Recommended Minimum Optimum Emulsion Contents

Emulsion	Lime Slurry (%)	Test Pit	Optimum Emulsion Content* (%)	Mix Water Content* (%)
Reflex	0.0	1 and 2	2.0	4.5
		3	2.0	3.0
HFMS-2P	3.3	1 and 2	2.0	1.2
		3	1.5	1.7

*Field adjustments to the emulsified asphalt content and /or mix water content may be required as the test results are representative of results obtained from RAP produced from crushed pavement sections and may or may not be representative of the actual millings from each project. RAP and aggregate base were tested in an oven dry condition and field samples will contain some moisture, possibly reducing mix water demand.

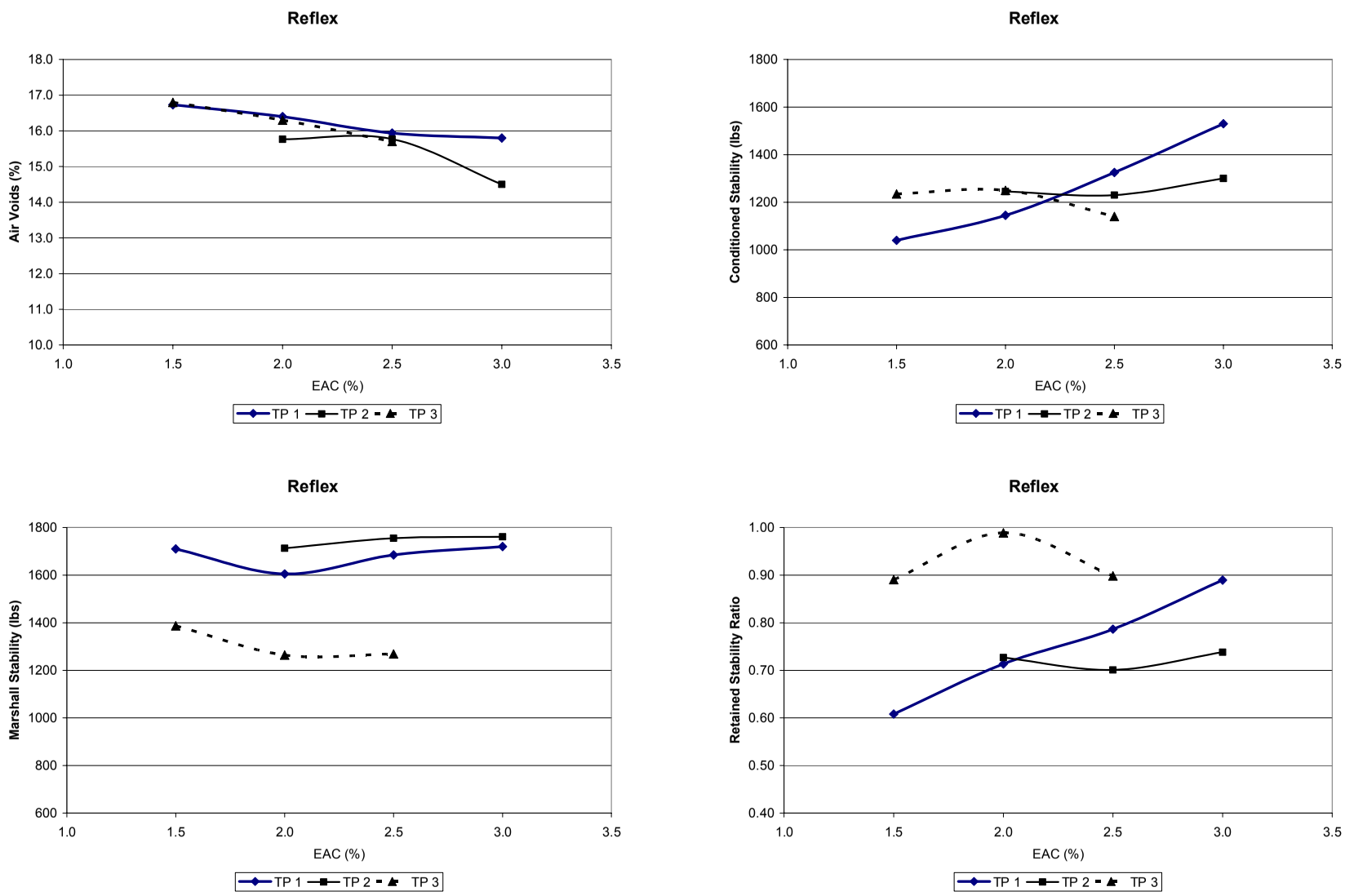

Figure 1. Results for Reflex emulsion.

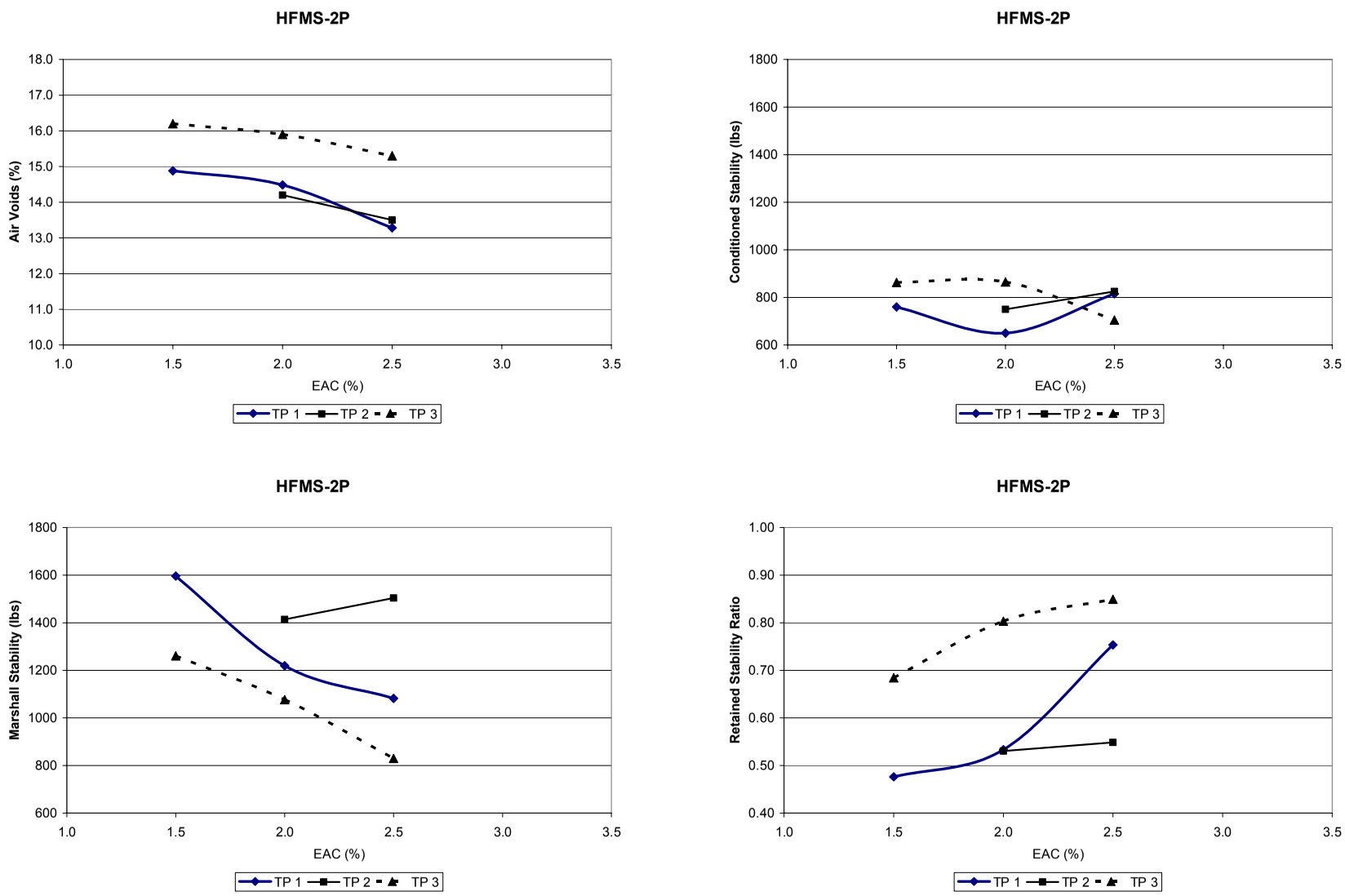

Figure 2. Results for HFMS-2P emulsion.

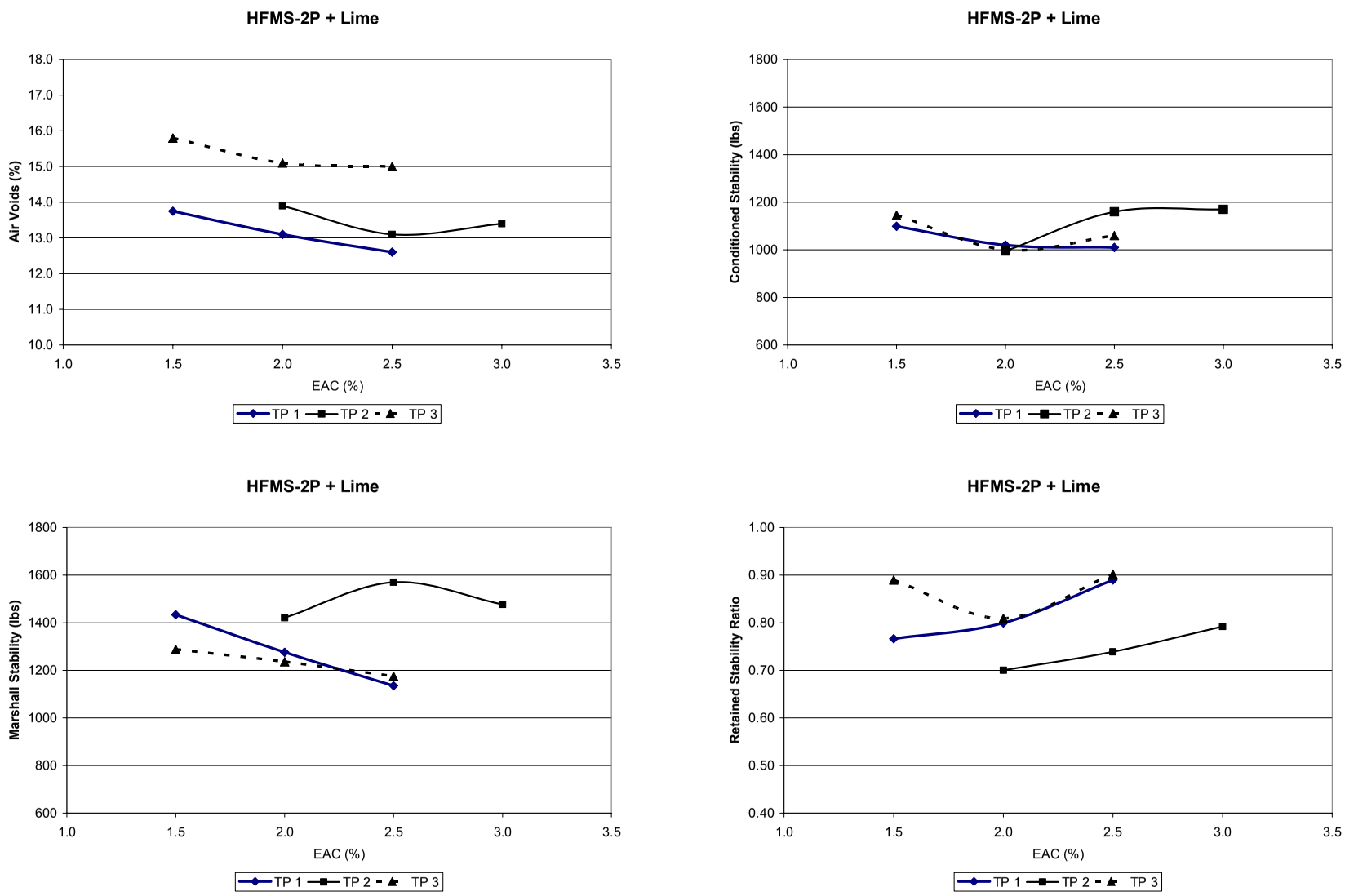

Figure 3. Results for HFMS-2P emulsion with lime.

Preparation of Lime Slurry Using Quicklime

The following method is used to prepare one liter of hydrated lime slurry from quicklime in the laboratory. The solids content of the slurry will be between 30% and 35% depending on the amount of water lost to evaporation during the slaking process. Slaking is the chemical reaction of quicklime (CaO) with water to produce hydrated lime [$Ca(OH)_2$]. This chemical reaction is exothermic or with considerable heat produced and the slurry temperature approaching or possibly exceeding the boiling point. Therefore, precautions must be taken to avoid eye or skin contact with the lime slurry. A greater or lessor amount of slurry can be prepared by proportionally increasing or decreasing the ingredient amounts.

Procedures: One Liter Total Volume of Slurry

1. Put on safety glasses and waterproof gloves.
2. Select a beaker or other mixing vessel with at least a 1200 mL capacity. This vessel should be able to withstand a temperature of at least 100°C (212°F). **Do <u>not</u> use an aluminum vessel.**
3. Add 924.6 g of water to the beaker or other mixing vessel and stir with a low shear mixer. Always keep the mixer running fast enough to move the slurry but not too fast so as to avoid "whipping" the slurry.
4. Add 277.4 g of quicklime to the water. The quicklime should be added uniformly and should take about 15 to 30 seconds to add.
5. Continue the mixing as the lime slakes. The temperature of the slurry will increase as the chemical reaction converts the quicklime to hydrated lime. The final temperature could approach or exceed boiling and some splattering of the slurry could occur.
6. After the temperature ceases to rise (usually within 15 minutes), the slaking reaction is completed. The slurry can now be used for laboratory testing.
7. Store the slurry in a tightly-capped polyethylene bottle if not to be used immediately.

Safety Note: If the lime slurry comes in contact with bare skin, wash immediately with cold water. Refer to the Material Safety Data Sheet (MSDS) for quicklime for the specific treatment.

Materials Needed to Make One Liter of Slurry

1. 1200 mL beaker or other similar size mixing vessel
2. 277.4 g of quicklime (CaO)
3. 924.6 g of water (H_2O)
4. Low shear mixer – Steadfast, Coframo, Hobart or similar type mixer
5. One liter polyethylene storage bottle
6. Laboratory thermometer, liquid immersion, maximum temperature of at least 110°C
7. Safety glasses and protective (waterproof) gloves