Table 4. Changes in percent passing the No. 200 sieve for granite and gravel.

SIEVE SIZE	JMF -2.8%	JMF -1.4%	JMF	JMF +1.4%
1/2 inch	100.0	100.0	100.0	100.0
3/8 inch	80.0	80.0	80.0	80.0
No. 4	29.0	29.0	29.0	29.0
No. 8	24.7	24.8	24.9	25.0
No. 16	18.4	18.6	18.8	19.0
No. 30	15.8	16.3	16.8	17.3
No. 50	13.8	14.6	15.4	16.2
No. 100	11.5	12.6	13.7	14.8
No. 200	7.4	8.8	10.2	11.6

Table 5. Changes in percent passing the No. 4 sieve for granite and gravel.

SIEVE SIZE	JMF-5%	JMF	JMF+5%	JMF+10%
1/2 inch	100.0	100.0	100.0	100.0
3/8 inch	79.0	80.0	81.0	82.0
No. 4	24.0	29.0	34.0	39.0
No. 8	22.9	24.9	26.9	28.9
No. 16	17.8	18.8	19.8	20.8
No. 30	16.0	16.8	17.6	18.4
No. 50	14.8	15.4	16.0	16.6
No. 100	13.4	13.7	14.0	14.3
No. 200	10.2	10.2	10.2	10.2

percent passing the No. 200 sieve and the No. 4 sieve, as outlined in Figure 6. Tables 4 and 5 indicate the various gradation changes made.

The following paragraphs describe in more detail the various modifications made in the SMA mixes.

Changes in Amount Passing the No. 200 Sieve

In order to determine the effect of aggregate gradation, changes in the amount passing the No. 200 sieve were made. The material passing the No. 200 sieve was obtained by screening a local agriculture lime. The amount passing the No. 200 sieve was varied from 7.4 to 11.6 percent for the granite and gravel aggregates. Table 4 shows the effect of changing the amount of material passing the No. 200 sieve on the total aggregate gradation.

Changes in Amount Passing the No. 4 Sieve

The percent passing the No. 4 sieve was varied from 24-39 percent for the granite and gravel aggregates. This is the range of most SMA mixtures that had been constructed in the U.S. prior to preparation of this report. However most recent projects have had less than 30 percent passing the No. 4 Sieve. Table 5 gives the gradation changes as a result of changing the amount of material passing the No. 4 sieve.

Changes in the Fiber Content

Samples were produced at the cellulose manufacturer's suggested fiber content of 0.3 percent by weight of total mixture. The fiber content was varied from 0.0 percent to 0.5 percent. For every change in the mix, the optimum AC content was determined, as stated before, to satisfy the air void content criteria. This approach was used so that information needed to determine the optimum fiber content could be developed.

Changes in the AC Content

The sensitivity of the mix to asphalt content was evaluated by varying the asphalt content for each JMF. The asphalt content was varied in 1/2 percent increments to 1 percent below and 1 percent above optimum.

The total number of mixtures that were evaluated for each aggregate-fiber type is shown below:

a.	Job mix formula (0.3 percent fiber, 29 percent passing the No. 4 sieve, 10.2 percent passing the No. 200 sieve and optimum asphalt content)	= 1
b.	Changes in fiber content	= 3
c.	Changes in percent passing the No. 4 sieve	= 3
d.	Changes in AC content	= 4
e.	Changes in percent passing the No. 200 sieve	= 3
	TOTAL	14

Therefore, the total number of SMA mixtures that were evaluated in the study for each fiber type and each aggregate type was 14. Since three fiber types and two aggregates were used, a total of 14x6= 84 SMA mixture types were tested. One dense graded mix was made for comparison purposes for each aggregate type, resulting in a total of 86 mixture types being evaluated.

For each mixture, 15 specimens were required for testing. However, 18 specimens per mix were prepared, and 15 selected for testing since some specimens were discarded due to unsatisfactory air voids. Figure 7 illustrates the estimated number of samples prepared for

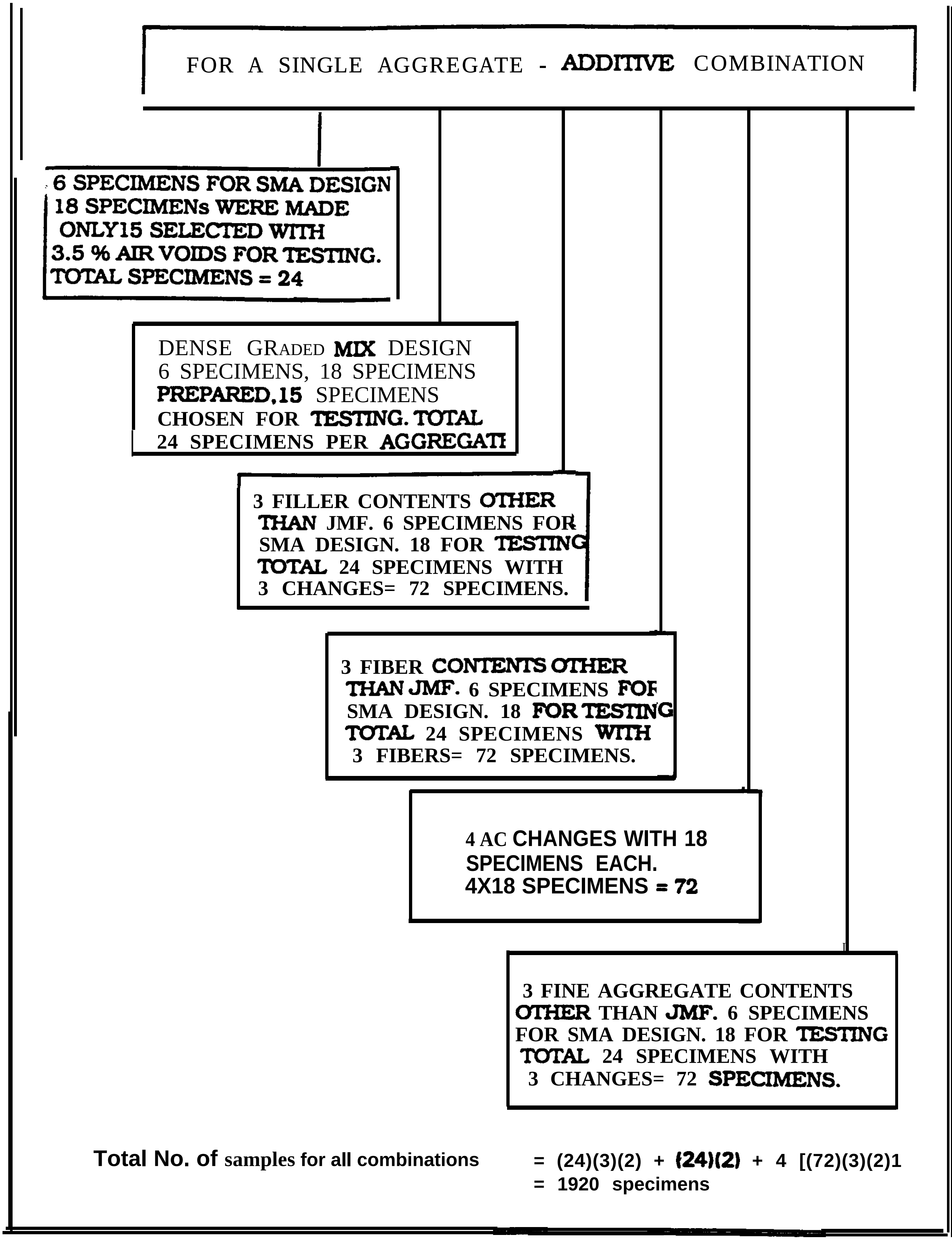

Figure 7. Estimate for the number of samples made.

testing in this study. The gradation for the granite and gravel dense graded mixtures are given in Table 6. The gradations were selected based on actual gradations of the materials submitted to the laboratory, therefore the two mixtures do not have the same grading. Both of these mixtures are typical dense graded mixtures and therefore, are acceptable for comparing to the SMA mixtures. The comparison of SMA and dense graded mixtures was not to evaluate which is better than the other but was made to help determine which tests may be applicable to SMA mixtures.

TESTS CONDUCTED

The following tests were conducted on samples of each mixture type:

1. Gyratory Properties (15 samples per mix. These tests were conducted during compaction and the samples were then used for other tests.):
   - i) Gyratory Shear Index (GSI).
   - ii) Gyratory Elasto Plastic Index (GEPI).
   - iii) Shear stress to produce 1 degree angle.
2. Stability and flow (3 samples).
3. Indirect Tensile strength at 77°F (3 samples).
4. Resilient Modulus at 40°, 77°, & 104”F (3 samples).
5. Creep:
   - a. Static confined at 140°F (3 samples).
   - b. Dynamic confined at 140°F (3 samples).

The 15 samples for each mixture evaluated were tested as illustrated in Figure 8. The test data obtained was analyzed to determine the effect of various mixture proportions on the laboratory properties.

Table 6. Gradations andmixpropetiies forgravel andgranite dense graded mixes.

	Granite Dense Mix	Gravel Dense Mix
Sieve No.	% Passing	% Passing
1/2 inch	100.0	100.0
3/8 inch	85.0	96.0
No. 4	67.0	82.3
No. 8	50.0	55.4
No. 16	30.3	35.7
No. 30	21.3	27.6
No. 50	15.0	17.8
No. 100	11.1	9.3
No. 200	6.7	5.6
T.M.D.	2.476	2.506
AC %	4.5	3.9
Bulk Sp.Gr.	2.372	2.413
Air Voids %	4.2	3.7

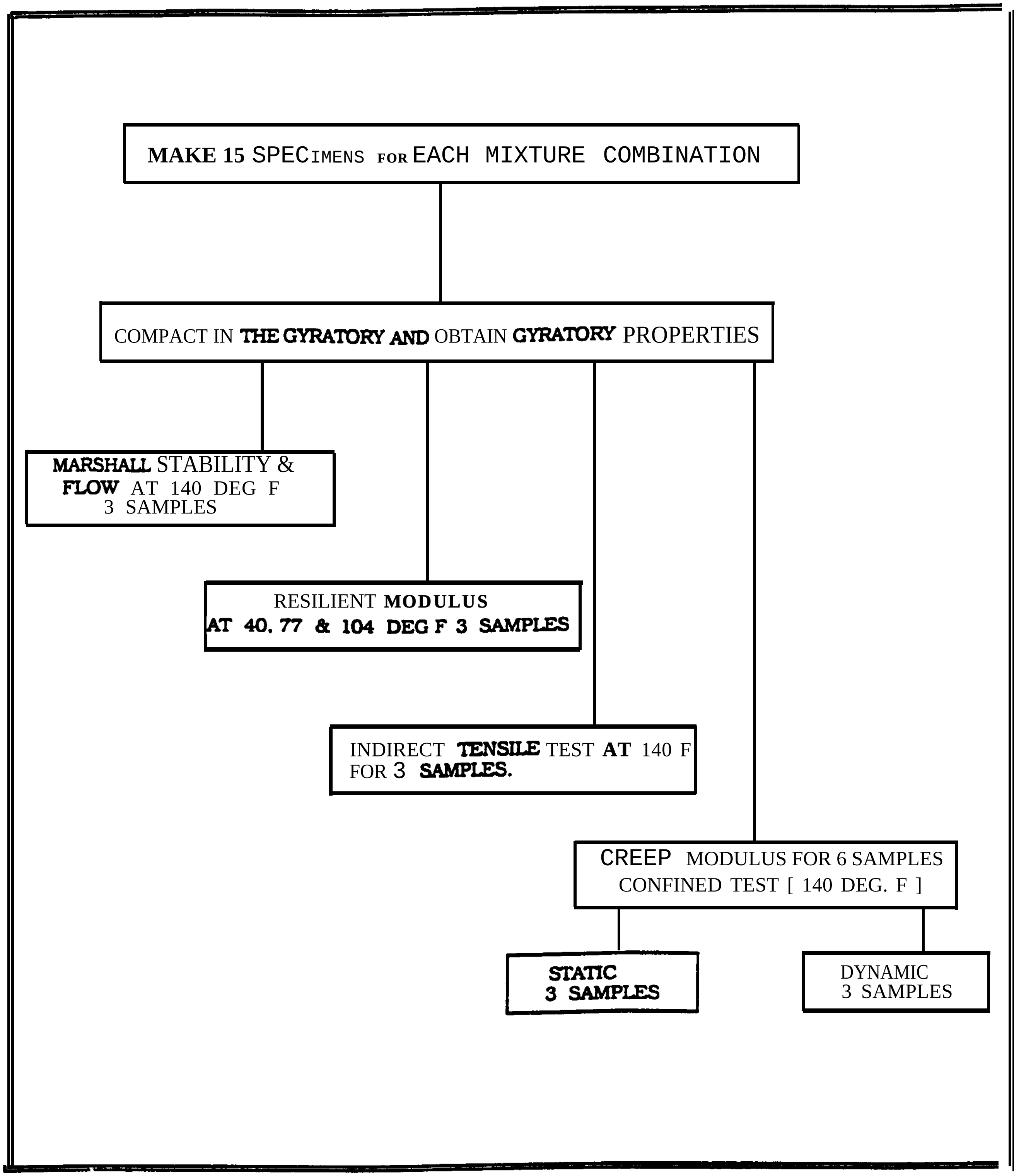

Figure 8. Flowchart for testing of mixture for each aggregate and material variation.

TEST RESULTS AND ANALYSIS

All tests were conducted as outlined in the previous section. A discussion of test results is provided in the following paragraphs.

VOIDS IN TOTAL MIX

The target air void content was 3.5 percent for all SMA mixes, except those in which the asphalt content was varied. Due to variability in the air voids for the SMA specimens, the acceptable range was set between 2.5 and 4.5 percent. Since there are too many factors which influence the variability in air void content it was not reasonable to control them closer than plus or minus one percent. Tables 7 through 12 list the void results along with the other test results for the various aggregate-fiber combinations. Figure 9a shows the trend for the granite aggregate mixtures for increasing AC contents. The SMA mixtures with mineral fiber (optimum AC = 5.5 percent) have lower optimum AC contents than those mixtures with cellulose fiber (optimum AC = 5.8 percent for both cellulose fibers). This optimum asphalt content is slightly below the recommended minimum of 6.0 percent. When this study was initiated it was felt that 3.5 percent air voids should be used and this may be true but most agencies are now using 3 percent air voids and this would have resulted in a higher optimum AC content. Use of mineral fiber results in mixtures having an optimum asphalt content approximately 0.3 percent lower than that for either of the cellulose fibers. Both cellulose fibers show similar trends. The reason for the higher AC content for the samples with cellulose fibers seems to be the bulking effect created by these fibers and/or some breakdown of the mineral fiber during mixing resulting in production of a filler size material causing a lower optimum asphalt content. The dense graded mixture for granite had an

Table 7. Summary sheet for Granite and American cellulose.

Project	Stone Matrix Asphalt							SUMMARY SHEET FOR GRANITE-AMERICAN CELLULOSE											
Mii Type (75 Rev.)			voids			Marshall Stability		Indirect Tensile strength		Resilient Modulus			static creep		Dynamic Creep		Gyratory Properties		
Changes	Asphalt Content (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	Stability	Flow	Pult @ 77F (lb)	Strength @ 77F (psi)	Modulus @ 40F (ksi)	Modulus @ 77F (ksi)	Modulus @ 104F (ksi)	Perm. strain (in\in)	creep Modulus (psi)	Perm. strain (in\in)	creep Modulus (psi)	0s1	GEPI	Shear Stress (psi)
Fiber, %																			
)	5.5	147.7	3.3	15.3	78.5	1472	16	2350	150.2	2394	495	“	0.0046	26087	0.0370	3243	Loo	Loo	39.22
).2	5.7	146.0	3.6	16.4	77.9	1403	16	1392	135.4	2335	897	“	0.0057	21053	0.0306	3922	1.00	1.10	36.00
).3	5.8	145.7	3.5	16.7	78.7	1437	15	163S	103.7	1506	374	“	0.0038	31579	0.0332	3614	1.00	1.10	33.85
).5	5.9	145.1	3.9	17.1	77.2	1434	15	1592	99.8	2215	457	“	0.0063	19048	0.0694	1729	1.(KI	1.09	35.32
AC, %																			
JMF-1%AC	4.8	144.6	5.8	16.4	64.5	1378	14	1670	105.0	1454	230	127	0.0069	17391	0.0295	4068	1.00	1.10	43.45
JMF-.5%AC	5.3	144.8	5.1	16.7	69.8	1322	16	1873	117.8	2237	378	85	0.0052	23077	0.0380	31s8	0.98	0.98	36.46
JMF	5.8	145.7	3.5	16.7	78.7	1437	15	1635	103.7	1506	374	“	0.0039	30769	0.0332	3614	1.00	1.00	33.85
JMF+.5%AC	6.3	146.7	23	16.5	86.1	1759	16	1883	120.0	2005	549	88	0.0098	12245	0.0841	1427	1.06	1.06	36.60
JMF+1.0%AC	6.8	146.6	1.6	16.9	90.3	1409	16	1708	108.8	2092	432	82	0.0064	18750	0.1305	919	1.00	1.00	35.80
% Passing No. 200																			
1.4	5.6	144.8	4.5	17.5	74.6	1239	13	1937	120.7	2002	312	78	0.0095	12632	0.0381	3150	1.03	1.03	40.40
3.8	5.6	144.5	3.8	16.9	n.4	1206	16	1818	112.7	13%	346	71	0.0115	10435	0.0629	1908	1.07	1.07	38.63
10.2	5.8	145.1	3.5	16.7	78.7	1437	15	1635	103.7	1506	374	“	0.0039	30769	0.0332	3614	Loo	1.00	33.85
[1.6	5.6	146.9	3.0	15.8	81.2	1468	12	1812	114.9	2310	338	100	0.0114	10526	0.0401	2993	1.01	1.01	33.61
% Passing No. 4																			
24	5.7	146.3	3.5	16.5	79.1	1260	17	1856	117.9	2463	342	81	0.0083	144s8	0.0555	2162	1.00	Loo	39.30
29	5.8	145.7	3.5	16.7	78.7	1437	15	1635	103.7	1506	374	“	0.0039	30769	0.0332	3614	Loo	1.00	33.85
u	5.6	146.8	3.3	16.2	79.7	1617	16	2233	143.3	2409	610	101	0.0085	14118	0.0580	2069	1.13	1.13	36.77
39	5.4	147.4	3.0	15.3	80.3	1405	15	2147	)37.9	2392	485	90	0.0104	11538	0.0708	1695	1.00	Loo	35.91
Dense Mix																			
100 Rev.	4.5	147.9	4.2	14.6	70.9	2500	12	2383	157.3	2301	413	117	0.0070	17143	0.0160	7477	Loo	1.10	40.70

“ Outliers

Table 8. Summary sheet for Granite and European cellulose.

Project:	Stone Matrix Asphalt								SUMMARY SHEET FOR GRANITE-EUROPEAN CELLULOSE										
Mix Type (75 Rev)			voids			Marshall Stability		Indirect Tensile Streng		Resilient Modulus			static creep		Dynamic Creep		Gyratory Properties		
Changes	Asphalt Content (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	Stability	Flow	Pult @ 77F (lb)	Strength @ 77F (psi)	Modulus @ 40F (ksi)	Modulus @ 77F (ksi)	Modulus @ 104F (ksi)	Penn Strain (in\in)	creep Modulus (psi)	Penn. strain (in\in)	Creep Modulus (psi)	GSI	GEPI	Shear Stress (psi)
Fiber, %																			
)	5.5	147.7	3.3	15.3	78.5	14722	16	2350	150.2	2394	495	"	0.0046	26087	0.0370	W			
).2	S.6	146.8	3.2	16.0	80.1	14000	12	1908	121.0	2281	308	86	"	"	0.0258				
).3	5.8	145.8	3.0	16.2	81.8	11533	14	1537	%.0	2131	305	73	"	"	0.0328				
).5	6.5	145.8	29	17.6	83.6	1456	14	1870	116.0	2005	257	91	"	•	0.0526				
AC, %																			
IMF-1%AC	4.8	144.6	5.8	15.9	67.8	13355	15	1717	107.0	18%	353	84	"	"	0.0395	3038	1.00	1.10	36.50
IMF-.5%AC	5.3	144.8	5.1	16.2	74.0	1127	16	1867	117.0	m 8	250	93	"	"	0.0541	2218	Loo	1.10	35.70
IMF	5.8	145.8	3.0	16.2	81.8	14722	14	1537	%.0	2131	305	73	"	"	0.0328	3659	1.00	1.10	3
IMF+.5%AC	6.3	146.2	23	16.3	87.77	1238	15	1738	109.0	2544	362	111	"	"	0.0679	1767	1.00	1.10	33.90
IMF+1.0%AC	6.8	147.3	0.8	16.2	%.3	1779	16	1795	115.0	2438	443	86	"	"	0.1558	770	1.00	1.10	34.40
% Paining No. 200																			
7.4	6.3	145.0	3.9	17.9	81.2	1371	14	1342	83.6	2310	263	78	"	"	0.097	1237	1.00	1.10	37.50
3.8	6.0	145.8	3.2	16.8	81.1	1439	16	1600	100.9	3563	285	89	"	•	0.0562	2135	1.00	1.10	35.70
10.2	5.8	145.8	3.0	16.2	81.8	1153	14	1537	%.0	2)31	305	73	"	"	0.0328	3659	1.00	1.10	38.33
11.6	5.8	147.2	28	16.1	827	1439	13	1817	116.0	2273	399	76	"	"	0.0629	1908	1.00	1.10	34.80
% Passing No. 4																			
24	5.5	145.8	4.3	16.6	74.6	1259	14	1563	99.0	1803	405	86	"	"	0.037	3243	1.00	1.10	3220
29	5.8	145.8	3.0	16.2	81.8	1153	14	1537	%.0	2131	305	73	"	"	0.0328	3659	1.00	1.10	38.33
34	6.0	146.5	3.3	17.0	80.5	1329	13	1633	103.0	2457	438	83	"	"	0.0671	1788	1.00	1.10	37.70
39	5.8	146.3	3.3	16.5	79.9	1309	14	1708	107.0	2436	315	71	•	"	0.0325	3692	1.00	1.10	35.20
Dense Mix																			
100 Rev.	4.5	147.9	4.2	14.6	70.9	2500	12	2383	157.3	2301	413	117	0.0070	17143	0.0160	7477	1.00	1.10	40.70

• Outliers

Table 9. Summary sheet for Granite and Mineral fiber.

Project:	Stone Matrix Asphalt									SUMMARY SHEET FOR GRANITE-MINERAL FIBER									
Mix Type (75 Rev.)			Voids			Marshall		Indirect Tensile Strength					Static Creep		Dynamic		Gyratory Properties		
Changes	Asphalt Content (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	Stability	Flow	Pull @ 77F (lb)	Strength @ 77F (psi)	Modulus @ 40F (ksi)	Modulus @ 77F (ksi)	Modulus @ 104F (ksi)	Perm. Strain (in\in)	Creep Modulus (psi)	Perm. Strain (in\in)	Creep Modulus (psi)	GSI	GEPI	Shear Stress (psi)
Fiber, %																			
0	5.5	147.7	3.3	15.3	78.5	1472	16	2350	150.0	2394	495	•	0.0046	26087	0.0370	3243	1.00	1.00	39.22
0.2	5.5	148.1	3.2	15.9	79.7	1418	12	1508	97.0	2741	656	87	0.0049	24490	0.0264	4545	1.00	1.10	34.90
0.3	5.5	148.1	2.6	15.2	83.3	1579	14	1608	104.0	2058	316	105	0.0066	18182	0.0275	4364	1.00	1.10	37.90
0.5	5.5	147.3	3.7	16.3	77.4	1753	14	1742	111.0	3007	758	109	0.0078	15385	0.0271	4428	1.00	1.10	35.80
AC, %																			
JMF-1%AC	4.5	146.5	5.1	15.3	67.0	1540	14	1683	107.0	2155	414	74	0.0049	24490	0.0261	4598	1.00	1.10	37.90
JMF-.5%AC	5.0	148.5	3.8	15.2	75.1	1453	12	1598	100.0	2845	534	97	0.0059	20339	0.0127	9449	1.00	1.10	39.40
JMF	5.5	147.7	2.5	15.2	78.5	1472	14	2350	104.0	2394	495	105	0.0066	18182	0.0275	4364	1.00	1.00	39.22
JMF+.5%AC	6.0	148.5	1.9	15.7	88.0	1457	13	1600	103.0	2093	451	83	0.0071	16901	0.0351	3419	1.00	1.10	35.50
JMF+1.0%AC	6.5	148.5	1.4	16.3	91.6	1438	16	1695	108.0	2512	561	90	0.0091	13187	0.1330	902	1.00	1.10	34.30
% Passing No. 200																			
7.4	6.2	145.8	4.0	17.8	77.6	1341	12	1537	95.0	1382	247	48	0.0054	22222	0.0262	4580	1.00	1.10	39.90
8.8	5.5	147.2	3.8	16.3	76.7	1417	12	1700	109.0	1264	268	59	0.0095	12632	0.0232	5172	1.00	1.10	39.90
10.2	5.5	148.1	3.3	15.2	78.5	1472	14	1608	104.0	2394	495	105	0.0046	26087	0.0370	3243	1.00	1.00	37.90
11.6	5.3	148.5	3.0	15.2	80.5	1860	13	1835	119.0	1243	279	80	0.0081	14815	0.0363	3306	1.00	1.10	37.70
% Passing No. 4																			
24	5.8	147.8	2.6	16.0	83.7	1400	17	1730	110.0	1258	354	115	0.0119	10084	0.0249	4819	1.00	1.10	37.30
29	5.5	148.1	3.3	15.2	78.5	1472	14	1608	104.0	2394	495	105	0.0066	18182	0.0275	4364	1.00	1.00	39.22
34	5.3	147.8	3.1	15.2	79.9	1538	13	2200	142.0	1179	381	56	0.0083	14458	0.0227	5286	1.00	1.10	39.60
39	5.3	148.0	3.3	15.5	78.6	1400	13	1833	118.0	2983	350	116	0.0118	10169	0.0244	4918	1.00	1.10	34.80
Dense Mix																			
300 Rev.	4.5	147.9	4.2	14.6	70.9	2500	12	2383	157.3	2301	413	117	0.0070	17143	0.0160	7477	1.00	1.10	40.70

Table 10. Summary sheet for Gravel and American cellulose.

stone Matrix **Asphalt**								SUMMARY **SHEET** FOR **GRAVEL-AMERICAN** CELLULOSE											
Type			voids			Marshall stability		Indirect Tensile Streng		Resilient Modulus			static creep		Dynamic Creep		Gyratory Properties		
hanges	Asphalt Content (%)	Unit Weight (pcf)	(%)	VMA (%)	P i i (%)	Stability	Flow	Pult @ 77F (lb)	Strength @ 77F (psi)	Modulus @ 40F (ksi)	Modulus @ 77F (ksi)	Modulu @ 104F (ksi)	Penn strain (in\in)	Creep Modulu (psi)	Perm. strain (in\in)	creep Modulu (psi)	GSI	GEPI	Shear Stress (psi)
	5.5	147.1	3.4	14.9	**77.0**	1435	13	**1683**	107.1	1574	252	66	**0.0092**	**13043**	0.0209	5742	1.00	1.15	43.89
	4.8	146.6	3.4	14.4	76.4	1201	**13**	1683	107.3	**1233**	236	**82**	0.0061	1%72	0.0261	4598	**1.00**	1.15	41.72
	4.7	146.6	3.6	14.4	74.9	1544	11	)633	103.9	1197	t%	63	0.0045	26667	0.0292	4110	1.00	1.15	44.83
	5.2	146.1	3.3	15.1	78.2	1513	12	1745	110.6	1337	267	67	0.0067	17910	0.0367	3270	**1.00**	1.18	46.18
JMF	3.7	144.6	6.6	14.9	55.8	**1526**	13	1424	**88.7**	**1297**	238	65	**0.0051**	23529	0.0141	8511	1.00	**1.20**	43.06
JMF	4.2	**145.0**	5.5	15.0	63.3	1824	14	1330	85.0	1290	255	64	0.0060	**20000**	0.0266	4511	Loo	**1.20**	46.9a
JMF	4.7	146.6	3.6	14.4	74.9	1544	**11**	1633	103.9	1197	1%	63	0.004s	26667	0.0292	4110	1.00	1.15	44.83
JMF	5.2	146.5	3.2	15.1	78.8	1335	12	1630	103.0	1312	249	43	0.0112	10714	0.0270	4444	Loo	1.14	44.14
JMF 0%	5.7	147.0	22	15.2	85.6	1410	11	1612	1025	1122	204	70	0.0082	14634	**0.0320**	**3750**	1.00	**1.20**	4244
Passing 200																			
	5.8	145.0	3.4	16.7	79.2	1245	13	1327	**84.5**	1347	380	**52**	0.0061	1%72	*0.0246*	4878	1.00	**1.20**	39.89
	5.2	147.0	3.1	14.9	79.9	1335	14	1158	73.8	1292	221	47	**0.0083**	**14458**	*0.0189*	6349	1.00	1.22	45.09
	4.7	**146.6**	3.6	14.4	74.9	1544	11	1633	103.9	**1197**	**196**	63	0.0045	26667	*0.0292*	4110	**1.00**	1.15	**44.83**
	4.2	147.9	29	13.9	79.1	1726	15	1453	93.5	12s5	202	- **80**	0.0034	35294	*0.0204*	**5882**	1.00	**1.20**	**45.20**
Passing																			
	5.0	146.2	3.7	15.1	7s.5	1351	14	**1775**	1120	1557	?30	51	0.0087	13793	*0.0207*	5797	Loo	1.20	41.89
	4.7	146.6	3.6	)4.4	74.9	1544	12	1633	103.9	1197	1%	63	**0.0045**	26667	*0.0292*	4110	1.00	**1.15**	44.83
	4.7	147.6	3.2	14.0	**77.3**	1899	15	1947	123.0	1847	32a	**68**	**0.0088**	13636	0.0216	5536	1.00	**1.20**	**41.88**
	4.8	**149.1**	25	13.6	81.9	1736	**11**	1572	103.0	1705	262	**87**	0.0100	**12000**	0.0360	2143	1.00	*1.25*	**44.35**
Dense Mix																			
300	3.9	150.6	3.7	128	71.4	3725	10	2192	1424	2254	298	*n*	0.0059	**20236**	0.0193	6218	1.00	*1.01*	40.53

" **Outliers**

Table II. Summary sheet for Gravel and European cellulose.

Project: stone **Matrix** Asphalt										SUMMARY **SHEET FOR** GRAVEL-EUROPEAN **CELLULOSE**									
Mix Type (75 Rev.)			Voids			Marshall Stability		Indirect Tensile Strength		Resilient Modulus			static creep		Dynamic Creep		Gyratory Properties		
Changes	(%)	unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)		Flow	Pult @ 77F (lb)	Strength @ 77F (psi)	us @ 40F (ksi)	Modulu @ 77F (ksi)	Modulu @ 104F (ksi)	Penn strain (in\in)	creep Modulu (psi)	Perm. strain (in\in)	creep Modulu (psi)	GSI	GEPI	Shear tress (psi)
Fiber, %																			
)	5.s	147.1	3.4	14.9	77.0	1435	**13**	1683	107.1	1574	252	66	0.0092	13043	0.0209	5742	1.00	1.15	43.69
).2	5.3	147.5	27	14.8	81.9	1275	13	1678	106.5	**1289**	211	52	**0.0100**	11964	0.0234	5128	**1.00**	**1.20**	4250
).3	5.3	147.3	27	14.8	**81.9**	1346	12	1445	927	1914	235	56	0.0113	**10619**	0.0285	4211	1.00	1.23	43.43
).5	5.4	**146.0**	3.2	15.5	79.2	1423	14	1448	920	1853	**228**	46	0.0141	8511	0.0299	4013	**1.00**	1.23	45.07
AC, %																			
JMF-1%AC	4.3	145.9	4.9	14.7	66.5	1465	14	1650	104.0	1479	236	**60**	0.0089	13483	0.0176	6816	**1.00**	**1.20**	46.44
JMF-.5%AC	4.8	**145.3**	4.7	15.5	70.1	1483	**11**	1791	111.0	1390	241	48	0.0067	17910	0.0194	6166	1.00	**1.20**	**41.29**
JMF	5.3	147.3	27	14.8	81.9	1346	12	1445	93.0	1914	235	56	0.0113	**10619**	0.02s5	4211	1.00	**1.20**	43.43
JMF+.5%AC	5.8	147.2	23	15.3	86.6	1380	12	1687	108.0	2296	**205**	**51**	0.0102	11765	0.0371	3235	**1.00**	**1.20**	39.95
JMF+1.0%AC	6.3	147.3	1.9	15.7	920	**1462**	**15**	1588	**102.0**	1633	**169**	44	0.0113	10619	0.0434	2765	1.00	1.40	38.74
% Passing No. 200																			
1.4	6.4	144.4	3.2	17.6	**81.8**	1167	**16**	1367	85.0	1378	**151**	35	0.0127	9449	0.0259	4633	1.00	**1.20**	3998
).88	**5.7**	146.1	29	16.0	823	1178	**13**	1597	**100.0**	1s38	**236**	47	0.0149	6054	0.0198	6061	1.00	**1.20**	40.42
10.2	5.3	147.3	27	14.8	81.9	1346	12	1445	93.0	1914	**235**	%,	0.0113	**10619**	0.0285	4211	1.00	**1.20**	43.43
11.6	4.9	147.2	3.3	14.5	n.4	1481	12	1688	107.4	)920	223	53	0.0162	7407	0.0273	43%	1.00	**1.20**	**47.70**
% Passing No. 4																			
24	5.9	**144.9**	3.4	16.9	79.7	1075	14	1492	94.0	1404	**201**	46	0.0130	9231	0.0250	4800	1.00	**1.20**	**40.70**
29	5.3	147.3	27	14.8	81.9	1346	12	1445	93.0	1914	235	56	0.0113	**10619**	**0.0285**	4211	1.00	**1.20**	**44.83**
M	5.0	147.4	3.0	14.5	79.0	1528	**11**	1583	1020	**209**	197	50	0.0119	10084	0.0310	3871	1.00	**1.20**	41.68
to	4.8	148.1	29	13.9	79.5	**1812**	13	**1700**	**111.0**	1600	244	65	0.0130	**9231**	0.0293	4096	**1.00**	120	U.35
Dense Ma																			
300 Rev.	3.9	**150.6**	3.7	128	71.4	3725	10	2192	**142.4**	2254	298	77	0.0059	20236	0.0193	6218	**1.00**	1.01	40.53

" **Outliers**

Table 12. Summary sheet for Gravel and Mineral fiber.

Project: stone Matrix **Asphalt**								SUMMARY **SHEET** FOR GRAVELMINERAL FIBER											
Mix **Type** (75 Rev.)			**Voids**			**Marshall Stability**		**Indirect Tensile Strength**		**Resilient Modulus**			static creep		Dynamic creep		**Gyratory Properties**		
Changes	Asphalt Content (%)	**Unit** Weight **(pcf)**	Total (%)	VMA **(%)**	**Filled** (%)	**Stability**	Flow	Puk @ 77F (lb)	Strength @ 77F (psi)	**Modulus** @ 40F **(ksi)**	Modulus @ 77F **(ksi)**	**Modulus** @ 104F **(ksi)**	**Perm.** strain **(in\in)**	creep **Modulus** (pi)	Penn. strain **(in\in)**	creep **Modulus** **(psi)**	GSI	GEPI	shear **Stress** (pi)
'iber, %																			
1	5.5	147.1	3.4	14.9	77.0	1435	13	1683	107.1	**1574**	232	66	0.0092	13043	0.0209	5742	1.00	1.15	43.89
).2	4.2	**147.4**	4.2	13.9	69.6	1654	13	1518	%.7	2025	198	75	0.0078	15385	0.0239	4633	1.01	**1.20**	38.30
1.3	4.6	147.9	3.3	13.7	76.5	1472	14	1725	110.1	**1902**	245	62	O.(KW2	13043	0.0180	6678	1.00	1.27	4203
).5	5.0	147.0	3.6	15.1	76.0	13%	12	1558	99.1	1427	187	52	0.0137	8759	0.0210	5722	1.00	1.24	40.48
\C, %																			
'MF-1%AC	3.6	144.9	6.5	14.8	55.7	1544	12	1317	826	1403	129	48	0.0093	12903	0.0124	**9677**	**Loo**	**1.13**	4236
'MF-.5%AC	4.1	146.7	4.7	14.1	66.7	1535	**11**	1558	98.7	1800	249	75	0.0044	27273	0.0111	10811	1.00	**1.20**	**40.40**
'MF	4.6	147.9	3.3	13.9	76.5	1472	**14**	1725	**110.1**	1902	245	62	0.0092	13043	0.01s0	6678	1.00	**1.27**	4203
'MF+.5%AC	5.1	148.2	23	14.1	83.7	1481	12	1638	105.8	1803	176	34	**0.0069**	17391	0.0128	9375	1.00	**1.20**	38.77
'MF+1.0%AC	5.6	147.8	**1.9**	14.9	87.3	1368	14	1337	87.0	2233	268	49	0.0089	13483	0.0353	3399	1.00	1.17	**39.20**
% Passing No. 200																			
'.4	5.6	145.2	3.9	16.3	75.8	14%	18	1425	89.1	2081	151	43	0.0080	**15000**	0.0180	6678	Loo	1.20	4232
:.8	4.8	146.3	4.2	15.0	723	1468	**15**	**1795**	113.0	1459	**215**	48	0.0047	25532	0.0214	5607	1.00	1.15	47.11
0.2	4.6	147.9	3.3	13.7	76.5	1472	14	**1725**	110.1	1902	245	62	0.0092	13043	**0.0180**	6678	1.00	**1.27**	4203
1.6	4.3	147.8	3.7	13.5	73.0	**1544**	12	1748	1122	1508	251	72	0.0075	**16000**	0.0134	7777	**1.00**	1.20	43.76
b **Passing** No. 4																			
'4	5.0	146.6	3.7	**15.1**	75.4	1435	**14**	1725	109.0	**1900**	253	60	0.0185	**6486**	0.0107	11215	1.00	**1.20**	46.92
9	4.6	147.9	3.3	13.7	76.5	1472	14	1725	**110.1**	1902	245	62	0.0092	13043	0.0180	6678	1.00	**1.27**	4203
4	4.3	147.6	3.9	13.8	71.6	1700	13	1n4	113.0	2184	292	66	0.0056	**21429**	0.0134	8955	**1.00**	1.12	41.63
9	4.4	148.1	3.5	13.6	74.5	**1912**	13	1782	115.8	2183	293	66	0.0167	7186	0.0200	6009	1.00	1.10	**45.01**
)ense Mix																			
00 Rw.	3.9	150.6	3.7	128	71.4	3725	10	2192	1424	22s4	298	77	0.0059	20236	**0.0193**	**6218**	**1.00**	**1.01**	**40.53**

• **Outliers**

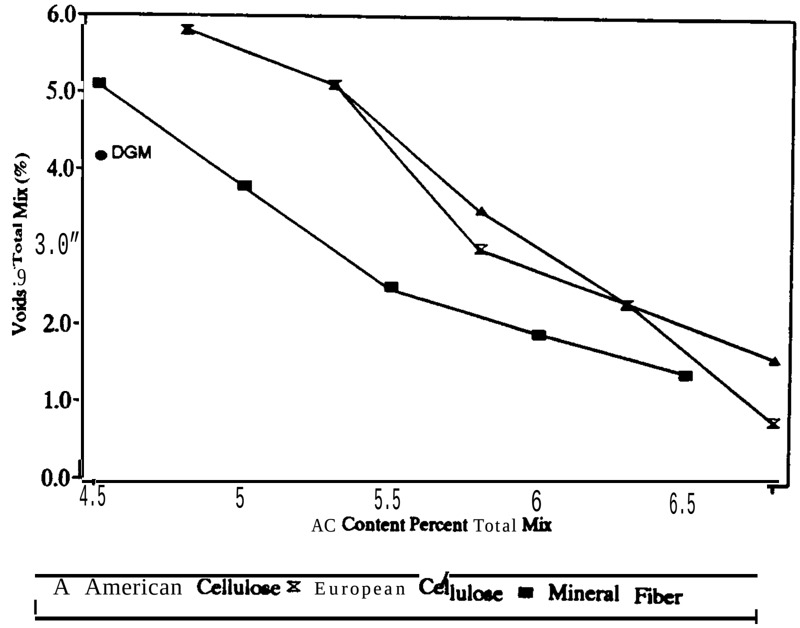

Figure 9a. VTM vs. AC content for Granite Aggregate

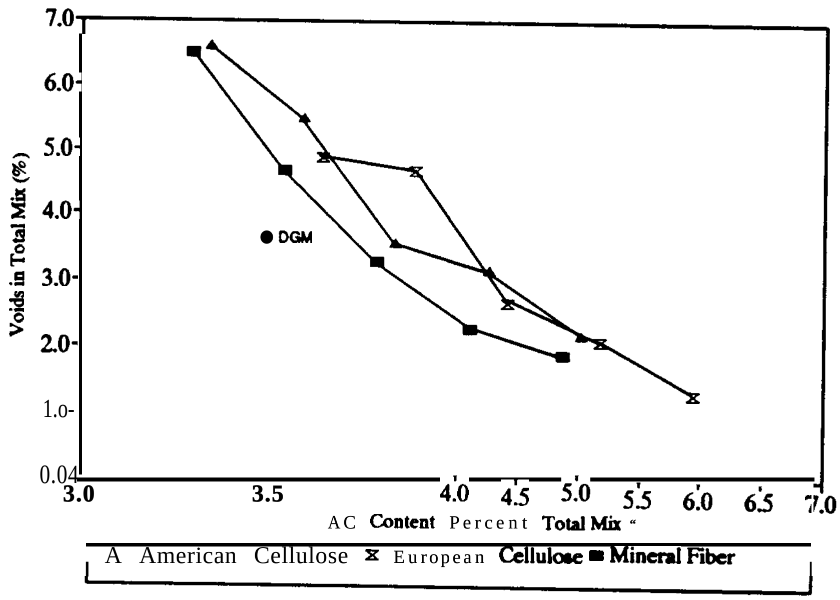

Figure 9b. VTM vs. AC content for Gravel Aggregate.

optimum AC content of 4.5 percent well below that for the SMA. This is one of the advantages of SMA, more AC can be added without the mixture becoming unstable.

The VTM versus AC content graph for the gravel mixtures shows a typical trend (Figure 9b). The VTM reduces as the AC content increases. The mixture containing gravel and mineral fiber had an optimum asphalt content of 4.6 percent compared to 4.7 percent for American Cellulose and 5.3 percent for European Cellulose. The dense graded mixture had an optimum AC content of 3.9 percent. This mixture tends to pack easily and the gradation would need to be changed or aggregates changed to get this optimum AC up to the minimum 6.0 percent recommended for SMA. As stated earlier the LA Abrasion of this aggregate is 46.5 percent which significantly exceeds the recommended maximum value of 30. This high LA Abrasion may have resulted in a closer packing of the aggregate and lower optimum asphalt content.

UNIT WEIGHT

Figures 10a and 10b indicate the trends for density for all the fibers. The unit weight is typically 2-3 pounds per cubic foot higher for the mixtures containing mineral fiber than for the two mixtures with cellulose. The two cellulose fibers show almost the same results. One possible reason for higher density for mineral fiber samples is the mineral fiber tends to breakdown during mixing generating filler material leading to higher density on compaction. Figures 1 la and 1 lb show that the unit weight for European cellulose and American cellulose samples generally decreases as the fiber content increases above zero. For the mineral fiber the unit weight increases to a peak at approximately 0.3 percent and then drops at higher fiber contents. This indicates that higher fiber contents tend to lower the density and thus increase the VMA. Higher fiber contents tend to lower the density by pushing apart the aggregate resulting in lower stability if the fiber content is too high.

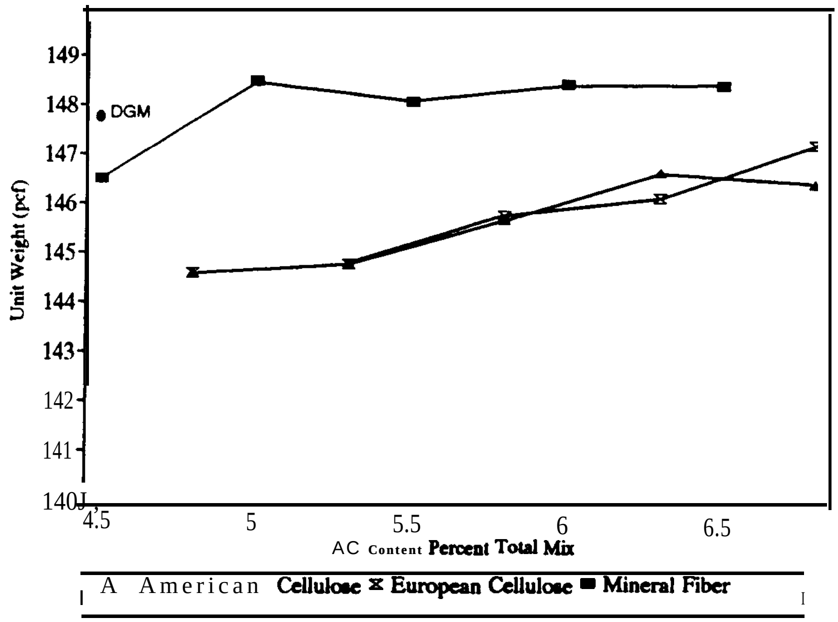

Figure 10a. Unit Weight vs. percent AC for granite aggregate.

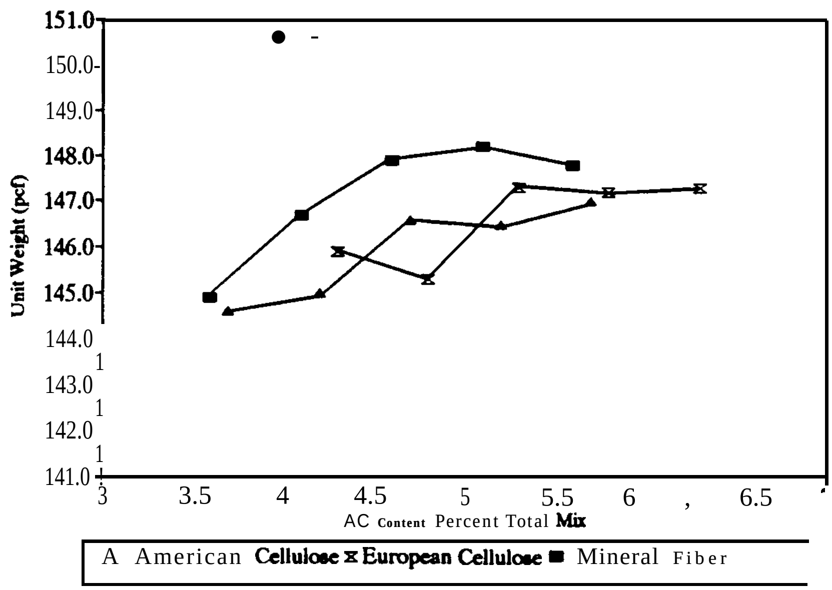

Figure 10b. Unit Weight vs. percent AC for gravel aggregate.

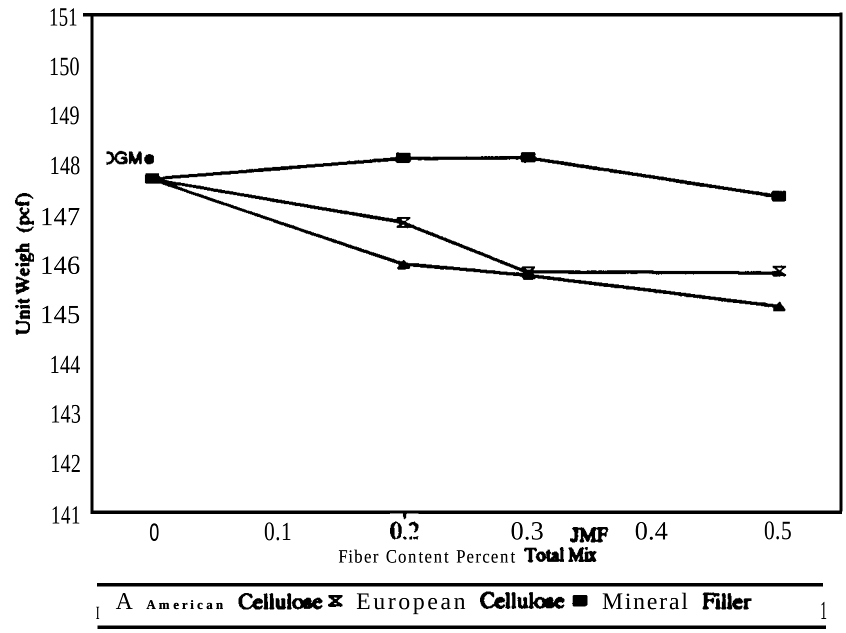

Figure 1 la. Unit Weight vs. Fiber Content for granite aggregate.

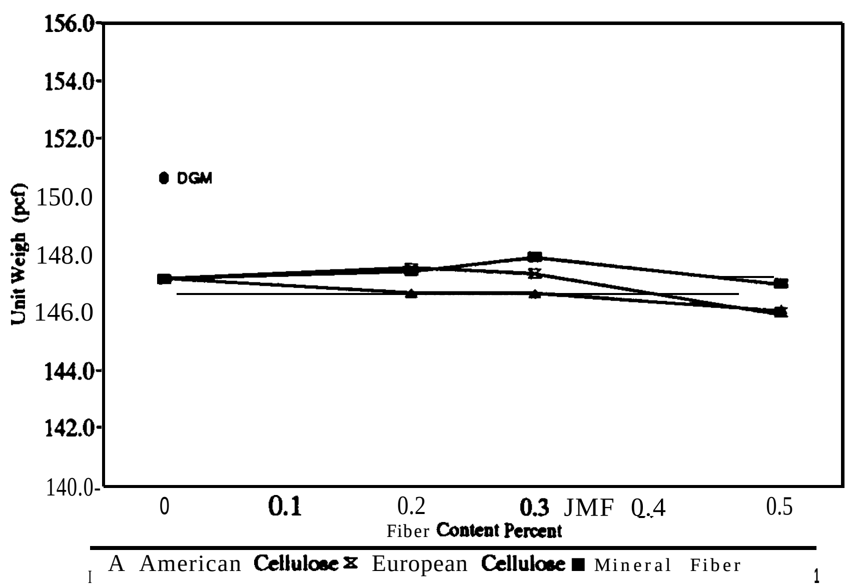

Figure 11 b. Unit Weight vs. Fiber Content for gravel aggregate.

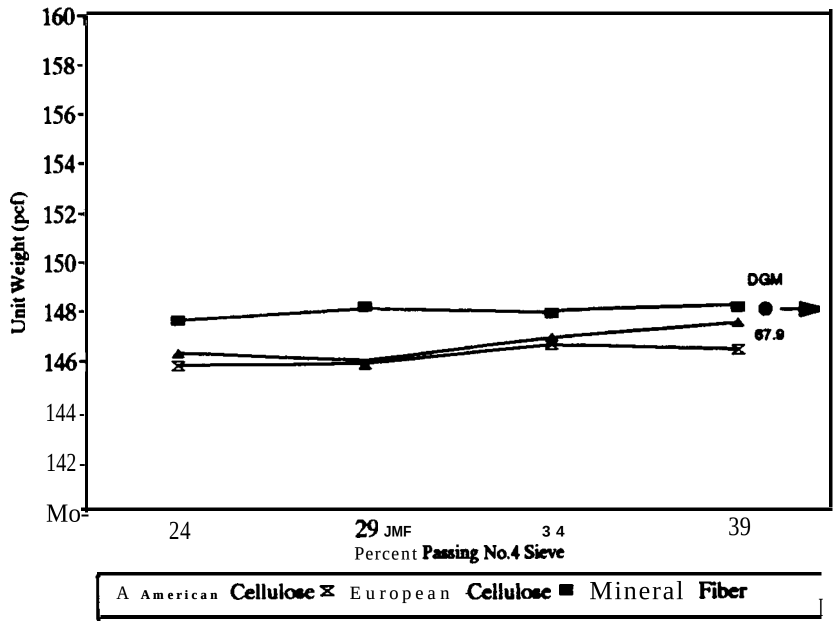

Figure 12a. Unit Weight vs. percent passing No. 4 sieve for granite aggregate.

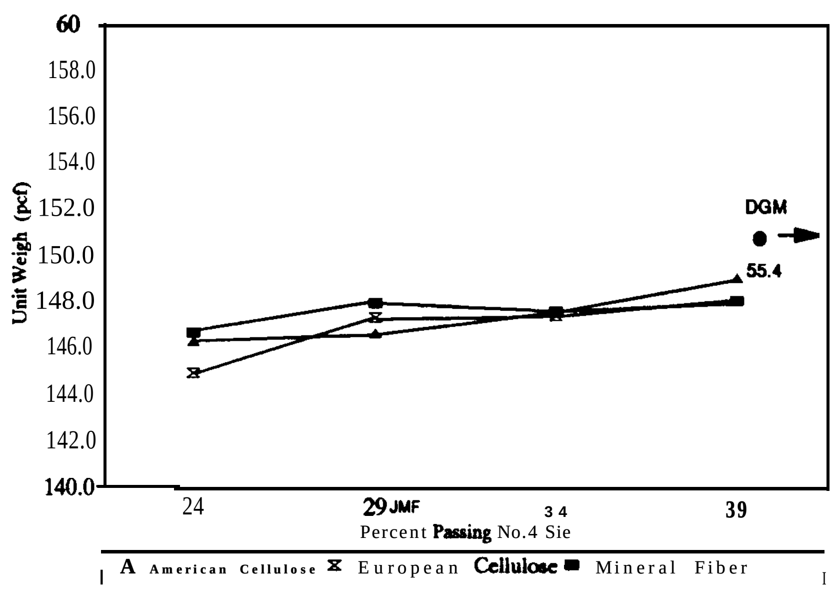

Figure 12b. Unit Weight vs. Percent passing No. 4 sieve for gravel aggregate.

Hence, the fiber content should be kept low enough so that the mixture is stable and high enough so that draindown of the AC does not occur.

Increasing the percent passing the No. 4 sieve results (Figures 12a & 12b) in an increase in unit weight for all three fibers, but as expected the density is higher for the mineral fiber. The granite aggregate shows very little loss in density with a decrease in percent passing the No. 4 sieve which indicates that stone-on-stone contact has probably not developed even when the percent passing the No. 4 sieve is reduced to 24 percent. The gravel mixture however shows a decrease in density with a decrease in percent passing the No. 4 sieve when the percent passing is reduced below 29 percent which indicates that stone-on-stone contact is beginning to develop as the fine fraction is reduced. When stone-on-stone contact develops, decreasing the percent passing the No. 4 sieve will simply increase the voids in the mineral aggregate resulting in a decrease in density since the coarse aggregate can not move closer together. Increasing the amount of material passing the No. 200 sieve also increases the unit weight of the SMA mixtures for both aggregates (Figures 13a and 13b). A decrease in the percent passing the No. 200 sieve results in a decrease in density but probably does not result in stone-on-stone contact as long as the percent passing the No. 4 sieve remains constant. In this case the loss in density is due to loss in voids in the fine aggregate portion and not a closer packing of the coarse aggregate portion which is necessary for stone-on-stone contact.

VOIDS IN MINERAL AGGREGATE (VMA)

Figures 14a and 14b illustrate the trend for VMA vs AC content. The VMA for the mineral fiber samples are lower than that for mixtures containing the cellulose fibers. An increase in VMA for an increase in asphalt content is caused by the asphalt cement pushing the aggregate apart. This can result in a loss in stability at higher asphalt contents. The gravel aggregate is being pushed

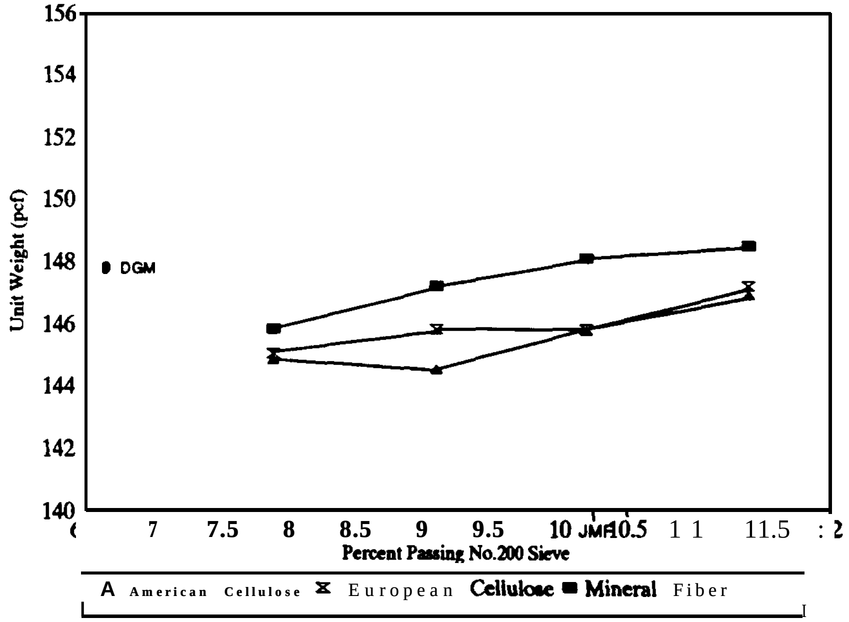

Figure 13a. Unit Weight vs. Percent passing No. 200 sieve for granite aggregate.

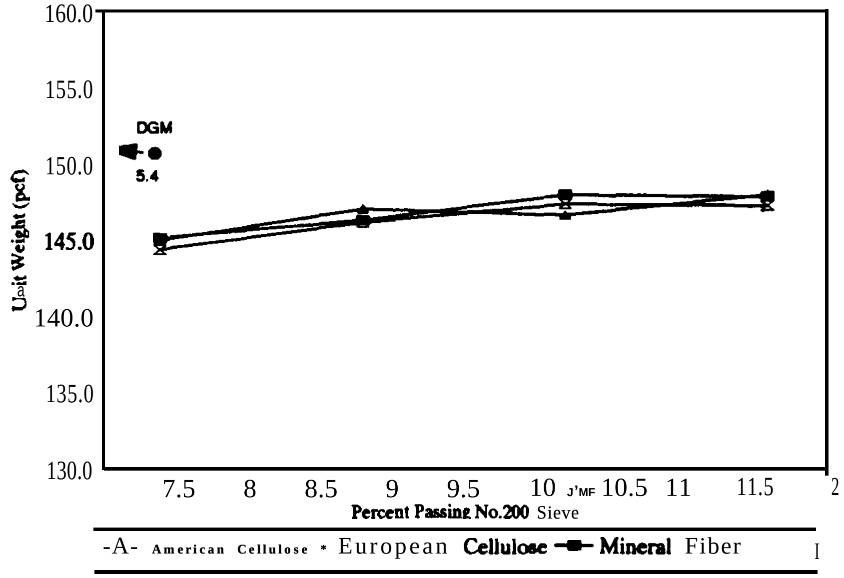

Figure 13b. Unit Weight vs. percent passing No. 200 sieve for gravel aggregate.

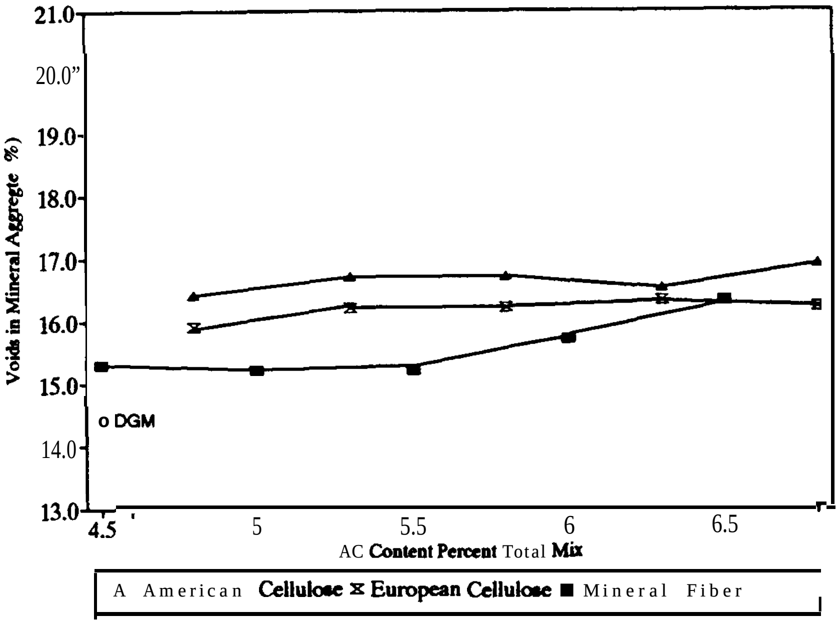

Figure 14a. VMA vs. AC content for granite aggregate.

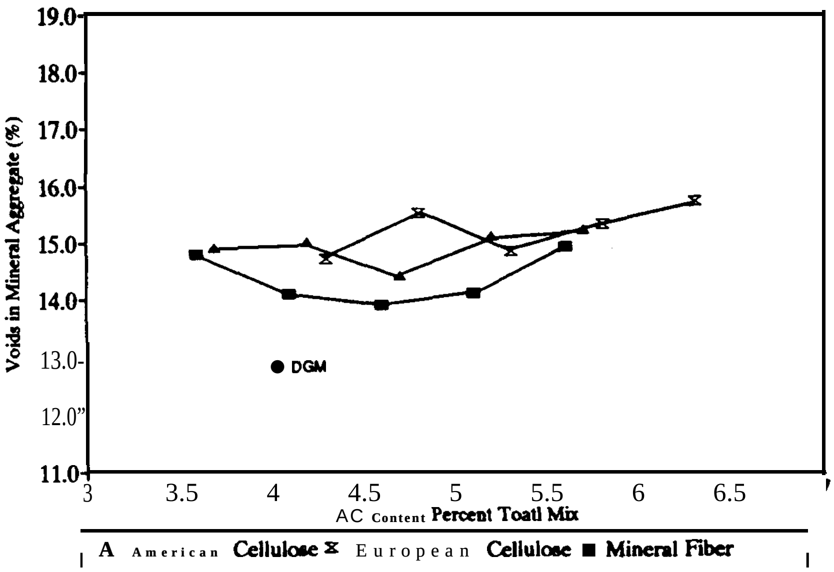

Figure 14b. VMA vs. AC content for gravel aggregate.

apart (higher VMA) at higher asphalt contents but this is apparently not occurring in the granite aggregate (no change in VMA) for the asphalt contents evaluated. The probable reason for this difference in the two aggregates is the higher VMA in the granite mixture. Figures 15a and 15b show the trend for VMA vs fiber content. The VMA is usually higher at high fiber contents. The fibers tend to push the aggregate apart at higher fiber content. Hence, the amount of fibers must be limited to some reasonable amount to prevent mixture instability. For the mixtures evaluated the aggregate generally begins to be forced apart at a fiber content above 0.3 percent.

An increase in the percent passing the No. 200 sieve (Figures 16a and 16b) results in a decrease in VMA. Mixtures containing mineral fiber produced lower VMA than mixtures prepared with cellulose fibers. So one way to decrease the VMA would be to reduce the amount passing the No. 200 sieve but if reduced too much, the asphalt cement may not be stiffened sufficiently by the filler to prevent draindown during construction.

An increase in percent passing the No. 4 sieve generally resulted in a decrease in VMA for the gravel aggregate but little change for the granite (Figures 17a and 17b). At some point the amount of VMA begins to increase with a reduction in the amount of material passing the No. 4 sieve. This point appears to be around 29 percent for both aggregates investigated in this study (Figures 17a and 17b). The VMA begins to increase with a reduction in the percent passing the No. 4 sieve because stone-on-stone contact begins to occur. For these two aggregates the percent passing the No. 4 sieve would have to be slightly below 24 to get a VMA of 17 which is sometimes specified as the minimum VMA for SMA. Once stone-on-stone contact begins to occur (increasing VMA) a small change in gradation during construction will significantly change the VMA and thus the voids in the mix. Hence, for the SMA mixture it is very important that the gradation be closely controlled.