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The Effect of Gradation and Fibre on the Performance of Open Graded Friction Course Mixes in Costa Rica

Authors: Donath Mrawira[1] and Monica Jimenez Acuña[2]

[1]Associate Professor & DC Campbell Chair for Highway Construction and Pavement Research, University of New Brunswick, Fredericton, NB, Canada. E3B-5A3.
Tel (506) 453-4976. Fax (506) 453-3568. Email: donath@unb.ca

[2]Laboratorio Nacional de Materiales y Modelos Estructurales (LANAMME), Universidad de Costa Rica, 400 metros norte Muñoz y Nanne, San Pedro de Montes de Oca, San José, Costa Rica.

Tel. (506) 207-4965, (506) 207-4251. Fax: (506) 207-4442.

E-mail: mjimenez@lanamme.ucr.ac.cr

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ABSTRACT

In Costa Rica the rainy season lasts approximately 8 months. This causes a serious safety problem in the principal highways due to hydroplaning and loss of visibility resulting from excessive water splash from heavy traffic. Open graded friction course (OGFC) mixes have been proposed in other countries to deal with this safety problem. This paper conducts laboratory evaluation of OGFC mixes to determine their suitability and assess engineering properties required to introduce these type mixes in Costa Rican pavement technology. The paper outlines Phase I of a larger investigation aimed at understanding performance of OGFC mixes in Costa Rica. In this phase, a full factorial experiment consisting of four gradations of a typical aggregate source, and three levels of fibre (no fibre, 0.5% of pellet cellulose fibre and 2% of lime) were evaluated. The mix designed was carried out according to SUPERPAVE at 100 gyrations using a typical Costa Rican asphalt binder (AC-30) modified with 1.5% of polymer. The mix performance was evaluated using the Asphalt Pavement Analyzer (APA) at two temperatures, and by the resilient modulus indirect tension test on conditioned/unconditioned specimens. The results obtained showed that the aggregate source, 0.5% fibre and 2% lime presented the lower permanent deformation and the highest Index of Retained Stiffness, which is a good indicator of the durability of the wearing course. The paper demonstrated that the use of 2% lime had statistically significant effect on both resilient modulus and resistance to permanent deformation of the OGFC mixes. Generally speaking, 2% lime was more beneficial to the mix compared to the use of 0.5% cellulose fibre. Small changes in the aggregate gradation, even as small as ± 2.5% retained on the 4.75 mm sieve, were found to have statistically significant effects on both rut resistance and resilient modulus of OGFC mixes.

INTRODUCTION

In Costa Rica the rainy season lasts approximately 8 months. This causes a serious safety problem in principal highways. The most common safety concerns are hydroplaning (loss of traction due surface water film) and loss of visibility resulting from excessive water splash from heavy traffic. Open graded friction course (OGFC) mixes have been proposed and successfully used in other countries to deal with this safety problem, dating back to 1940s. Despite that long history and popularity of OGFC mixes in other parts of the world, in Costa Rica these mixes have not been applied.

Open graded friction course (OGFC) mix is defined as a thin permeable hot rolled asphalt layer that is applied to a finished pavement to provide surface water removal, increase skid resistance and reduce noise of high volume high speed roads. Typically, OGFC mixes are designed to consist of between 18% and 25% of interconnected air voids that permit sub-surface water drainage to the lateral zones of the pavement *(1)*. The improved surface drainage reduces hydroplaning, splash and spray behind vehicles, improves surface reflectivity and reduces traffic noise *(2)*.

In order to achieve the high percentage of air voids, OGFC mixtures utilizes very low filler content, typically between 2 and 5 percent *(3)*. Also, the aggregate skeleton is comprised of gap-graded gradations; between 50% to 60% of the course aggregate been of the same size in the 9.5 mm to 4.75 mm sieve sizes.

The advantages can be summarized as

- Reduction of hydroplaning: the open mix absorbs and eliminates the surface water to the lateral zones of the pavement, improving the contact between the tire and the pavement surface.
- Increase of skid resistance: the surface after the construction gets smooth and level, the high content of voids provides a macrotexture in the order of 1.5 to 2.5 mm measured in the sand spot test, which provides a good interaction tire-pavement at high speeds.
- Reduction of spray and splash: the water flows to the interior of the layer and it drains to the shoulder throughout the interconnected voids, whose maintain the surface free from water and eliminate the spray and splash behind the vehicles and affect directly in the visibility and safety of the driver.
- Reduction of the glare caused by the vehicle lights in the presence of water the light reflects easily on the even surfaces, as open mixes drain the water the effect of reflectivity is eliminated so the visibility improves.
- Reduction of the noise: given the conditions of these mixes they absorb the noise with the consequent reduction producing a friendly environment.

In contrast of the advantages mentioned before, the disadvantages are the reduction of the durability cause by the exposure of the mix to a greater age hardening and oxidation by the environmental agents. Also the mix is more expose to the loose of asphalt-aggregate bonding for the water damage. Finally, the accelerated post-compaction is another disadvantage causing a problem similar to permanent deformation.

Kandhall et al. *(4)* found that half of the states surveyed indicated good experience with OGFC. More than 70% of the states reported service life of 8 or more years. A vast majority reports good experience using polymer modified asphalt binders.

OBJECTIVE

The primary objective of the study was to found the better composition of the open graded friction course mixes to introduce its use in the pavement technology of Costa Rica. In order to achieve this goal another tasks were to (1) determine the mix composition with the combination of 4 different gradations for one source of aggregate, an AC-30 asphalt modified with 1.5% of EGA polymer, 0.5% of cellulose fiber (pellets) and 2% of lime, (2) evaluate the performance with the APA test for permanent deformation at two temperatures and two cycles, resilient modulus by indirect tension test on unconditioned specimens and also with one cycle of moisture conditioned specimens, called Index of Retained Stiffness (IRS) and (3) recommend the better mix for the Costa Rican conditions that can be used for production and construction of a test section at one of the 4 principal highways.

SCOPE

A literature review was made to find out about the past research in the next subjects: mix design procedures, materials specifications for the OGFC's production and construction. In the first section of this paper the principal findings were summarized.

A laboratory study was conducted to answer questions such as: Are Costa Rican aggregates produced for dense graded mixes adequate OFGC of acceptable quality? Do they meet the international specifications? Is the asphalt content going to be much more compared to a dense mix? Is the mix going to be resistance to water damage (stripping)? Would the mix going have acceptable performance in terms of stability/rutting?

A statistical multi-factor ANOVA analysis for 4 and 3 factors was conducted and Tukey's multiple range tests to determine the significant differences in the performance and mixture volumetric properties of the 12 mixes.

RESEARCH METHODOLOGY

The flow chart presented in Figure 1 summarized the test plan for the laboratory study. In the first phase of the research, 3 blends were prepared to choose the optimum gradation based on the $VCA_{mix} < VCA_{DRC}$, also to achieve an air voids content between 20 and 22% and a draindown potential lower than 0.3%.

Then, the chosen gradation was studied with other two gradations with a difference of +2.5% and +5.0% in the passing percentage in the 4.75 mm sieve size, these gradations are shown in Figure 2, which are very similar to others like NCAT #3 *(2)* or the Australian specification OGA 10 *(5)*. The mixes were prepared with a modified PG-76 (10) asphalt binder (the specification for low temperature is not use in Costa Rica, but a specification for an intermediate temperature was obtained presented in the parenthesis) also with 0.5% cellulose fiber by weight of aggregate minus the percentage of binder that the pellets bring by themselves. The mix designs were conducted according to the FHWA procedure *(6)*, with 100 gyrations of the SGC.

In the second phase, another gradation was added with finer characteristics and the samples were tested for rutting at two temperatures and two cycles, resilient modulus by indirect tension on unconditioned specimens and also with one cycle of moisture conditioned specimens called Index of Retained Stiffness (IRS), in addition all mixes were prepared with 2% of lime, with the primary objective of evaluate the relative improvements in the mix properties obtained in the first part of the study, to achieve the better one.

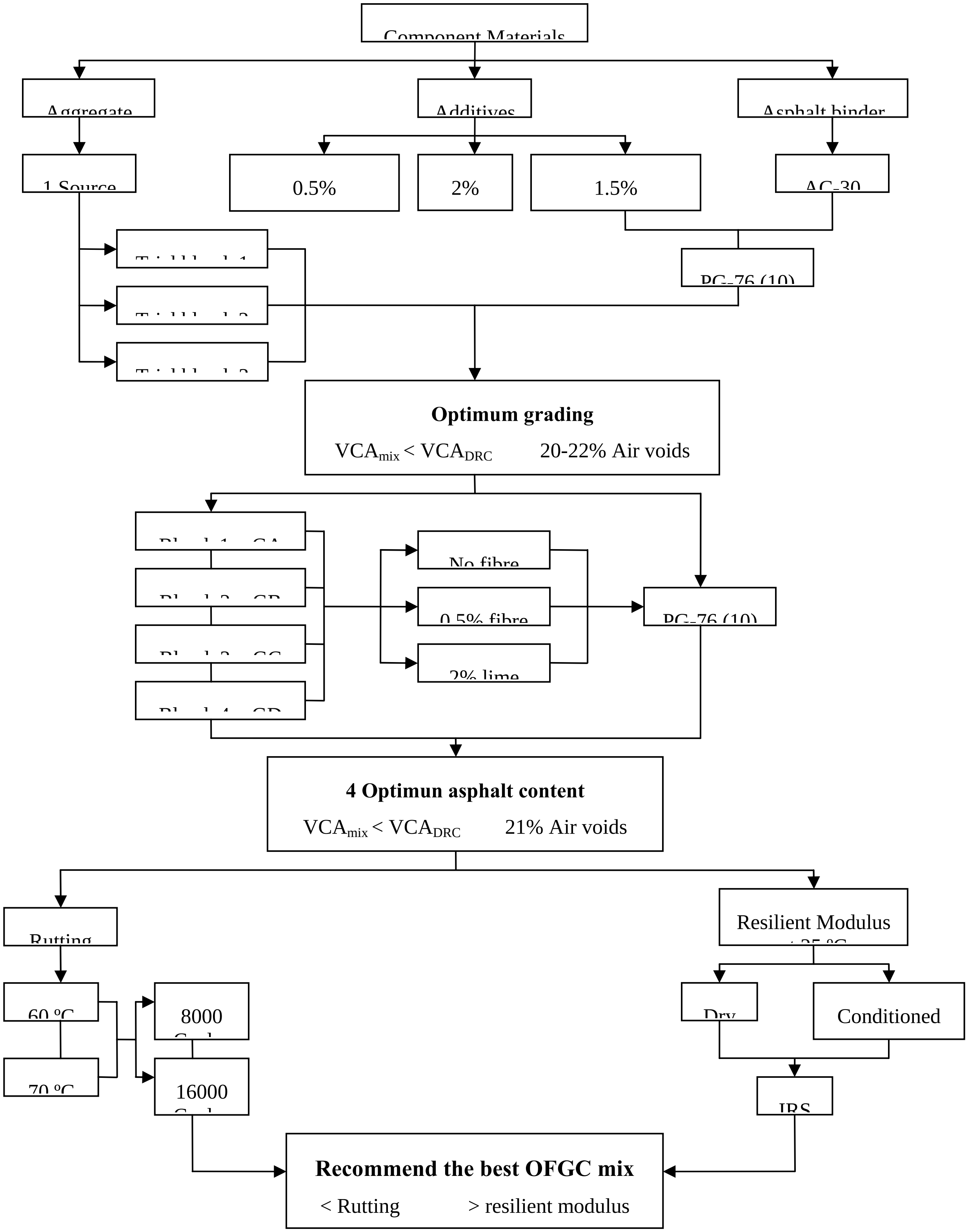

FIGURE 1 Flow chart of the test plan.

LAB DATA ANALYSIS

Aggregate Characterization

The study involved one source of aggregate come from a region at the northeast of the country called Guapiles. The aggregate is extruded from the river in the igneous deposits.

The aggregate properties are shown in Table 1.

TABLE 1 Physical properties of the aggregates used in the study

Property	Test Method	Value	Specifications
Coarse			
L. A. Abrasion	AASHTO T 96	21%	37% max.[1]
Specific Gravity	AASHTO T 85	2.65	2.85 max.[1]
Absorption	AASHTO T 85	1.7%	4% max.[1]
1 or More Faces Fractured	ASTM D 5821	100%	90% min.[2]
2 or More Faces Fractured	ASTM D 5821	99.8%	75% min.[2]
Fine			
Plasticity Index	AASHTO T 90	NP	10 max.[1]
Sand Equivalent	AASHTO T 176	78%	-
Angularity	AASHTO TP 33	37.2%	-
Specific Gravity	AASHTO T 20	2.55	2.85 max.[1]
Absorption	AASHTO T 20	3.3%	-

[1] Nevada DOT Standard Specifications for Road and Bridge Construction, 2001.
[2] Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects, FP-03.

Asphalt Binder Properties

In Costa Rica only one type of asphalt binder is produced. The binder viscosity classification is AC-30 unmodified, for the Superpave binder characterization is a PG 70 (13). The specification for low temperature is not used, but a specification for an intermediate temperature was obtained and is presented in the parenthesis. For the study, the AC-30 was modified with 1.5% of an EGA polymer, resulting on a PG 76 (10). The properties and Superpave classification for the asphalt binder are shown in Table 2.

Phase One, Selection of the Optimum Gradation

Three trial blends were chosen to found the optimum aggregate grading and four asphalt contents were used 3.5%, 4.0%, 4.5% and 5.0% by total weight of aggregate. The percent of voids of the compacted mixture (VCA_{mix}) is less than the voids of the coarse aggregate (VCA_{DRC}) in the dryrodded test, the achieving of a percentage of air voids in the compacted mix between 20 and 22% and the percentage of less than 0.3% in the draindown test were the criterion to choose the optimum gradation. Table 3 shows the summary of these results.

The trial blend 1 didn't obtained the $VCA_{mix} < VCA_{DRC}$ and also for the higher asphalt content presented problems of draindown. The other two trial blends didn't presented problems with draindown and the $VCA_{mix} < VCA_{DRC}$, however, the trial blend 2 were choose like the optimum gradation because it presented the percentages of air voids near the range of 20 and 22% with the lower draindown percentages.

TABLE 2 Performance grade properties of the modified asphalt used in the study

High Temperature Properties					Intermediate Temperature Properties		
Temperature (ºC)	**Original condition G*/sin δ (kPa)**	**Phase angle δ (º)**	**RTFO condition G*/sin δ (kPa)**	**Phase angle δ (º)**	**Temperature (ºC)**	**RTFO + PAV condition G*·sin δ (kPa)**	**Phase angle δ (º)**
58	7.610	70.5	21.110	64.6	16	2757	41.8
70	2.050	73.2	5.750	67.0	22	1541	44.6
82	0.670	76.3	1.860	69.9	28	878	48.2
PG	**76 (77.67 ºC)[1]**		**76 (80.02 ºC)[1]**		**PG**	**10 (9.42 ºC)[1]**	

[1] The actual temperature not rounded to the PG grade.

TABLE 3 Summary of the mix volumetric properties for the trial blends

	Gradation by Sieve Sizes										
	25.0 mm	**19.0 mm**	**12.7 mm**	**9.5 mm**	**4.75 mm**	**2.36 mm**	**1.18 mm**	**600 µm**	**300 µm**	**150 µm**	**75 µm**
TB 1	100	100	100	75	25	10	8	6.5	5.4	4.6	4
TB 2	100	100	92.5	65	17.5	7.5	6	4.9	4.1	3.4	3
TB 3	100	100	85	55	10	5	4	3.3	2.7	2.3	2

Volumetric Properties	TB 1				TB 2				TB 3			
Asphalt	3.5	4.0	4.5	5.0	3.5	4.0	4.5	5.0	3.5	4.0	4.5	5.0
Air Voids	23.6	22.2	20.0	20.8	23.0	23.5	22.4	21.8	25.3	24.4	24.9	23.9
VCA_{mix}	46.1	46.0	45.1	46.3	40.4	41.5	41.5	42.0	37.6	37.7	38.6	38.6
VCA_{DRC}	43.4				43.1				43,1			
Draindown	0.049	0.068	0.107	0.325	0.029	0.029	0.056	0.058	0.039	0.087	0.092	0.197

Superpave Mix Design

In order to obtain the optimum percentage of asphalt in the mixture for the optimum gradation GA (17.5%), the samples were compacted with 100 gyrations. Two new blends GB (20%) and GC (22.5%) were incorporated with the objective of study the gradation influence on the volumetric properties of the mixture. These gradations were chosen with a change of +2.5% and +5.0% in the passing percentage on the 4.75 mm sieve size. Also these phase included a study of the influence of the cellulose fiber in the mix design. Figure 2 shows the gradations used in these phase.

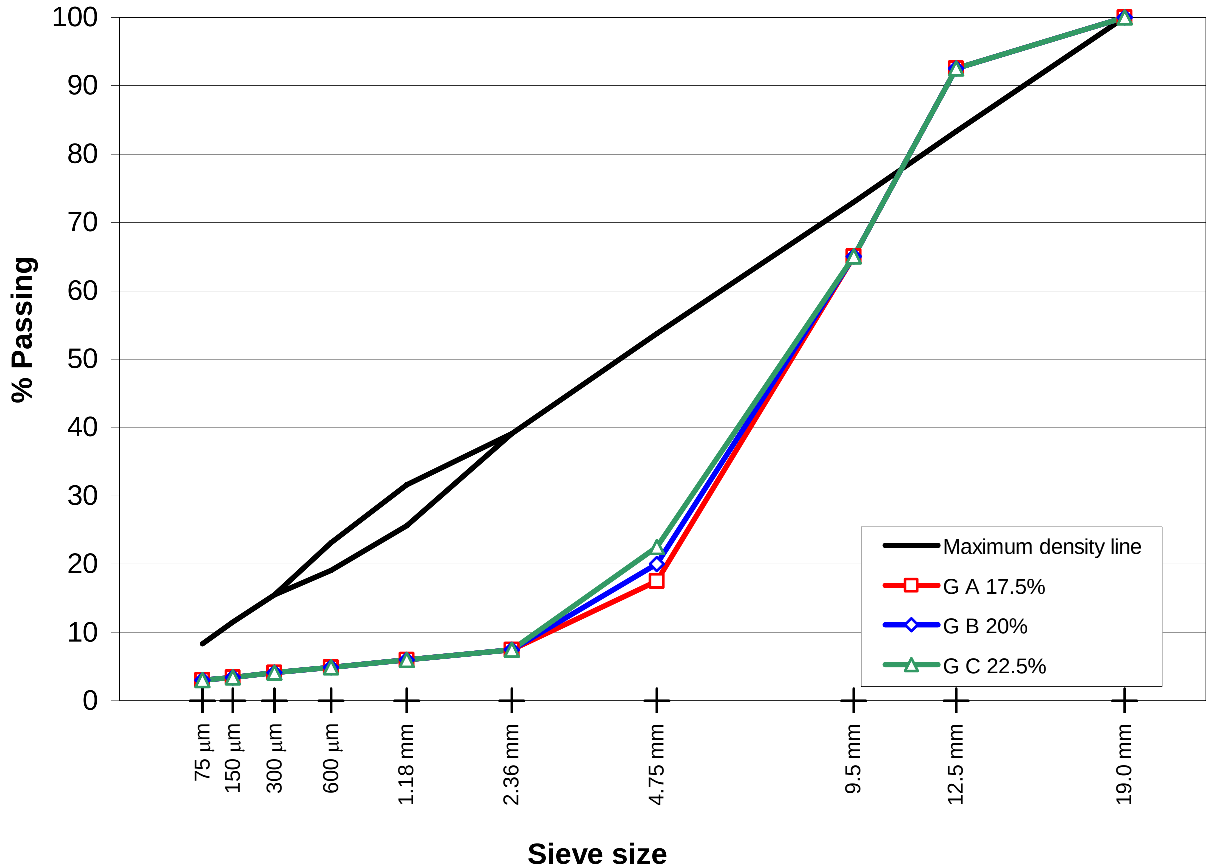

FIGURE 2 Gradations used in the first phase of the study.

The design air voids were fixed to 21%. The optimum asphalt content by total weight of aggregate, voids in the mineral aggregate (VMA), the voids filled with asphalt (VFA), the density and the draindown percentage are presented in Table 4, including the two conditions; no fiber and 0.5% fiber. The summary indicates that a little difference (a maximum of 0.7%) exists on the optimum asphalt content for the three gradations, the VMA remains almost constant also the VFA. The 0.5% of fiber affects the density by reducing it an average of 19 kg/m^3. The Schellenberg drainage test was conducted on the loose mixes at 175 ºC, as expected the mix with 17.5% passing the 4.75 mm sieve showed the maximum draindown potential but the addition of the fiber improved in a great percentage the draindown.

TABLE 4 Summary of the mix volumetric properties for the gradations A, B and C

	G A		G B		G C	
	No Fibre	**0.5% Fibre**	**No Fibre**	**0.5% Fibre**	**No Fibre**	**0.5% Fibre**
Asphalt (%TWA)	6.0	6.0	5.4	5.5	5.3	5.8
Air voids (%)	21.0	21.0	21.0	21.5	21.0	21.0
VMA (%)	30.0	30.7	29.1	30.2	29.4	30.0
VFA (%)	30.3	31.5	29.5	28.7	28.6	30.5
Density (kg/m^3)	1946	1928	1958	1935	1950	1935
Draindown (%)	0.83	0.18	0.16	0.17	0.13	0.33

Phase Two, Additional gradation and the modification of the mixes with 2% lime

In the second phase, an additional gradation (GD) was studied, with finer characteristics, with the purpose of compare between GA, GB and GC. All mixes were prepared with 2% of lime, with the primary objective of evaluate the relative improvements in the mix properties obtained in the first part of the study, to achieve the better one.

Figure 3 shows the additional gradation and Table 5 shows a summary of the volumetric properties for all mixes including the lime mix designs.

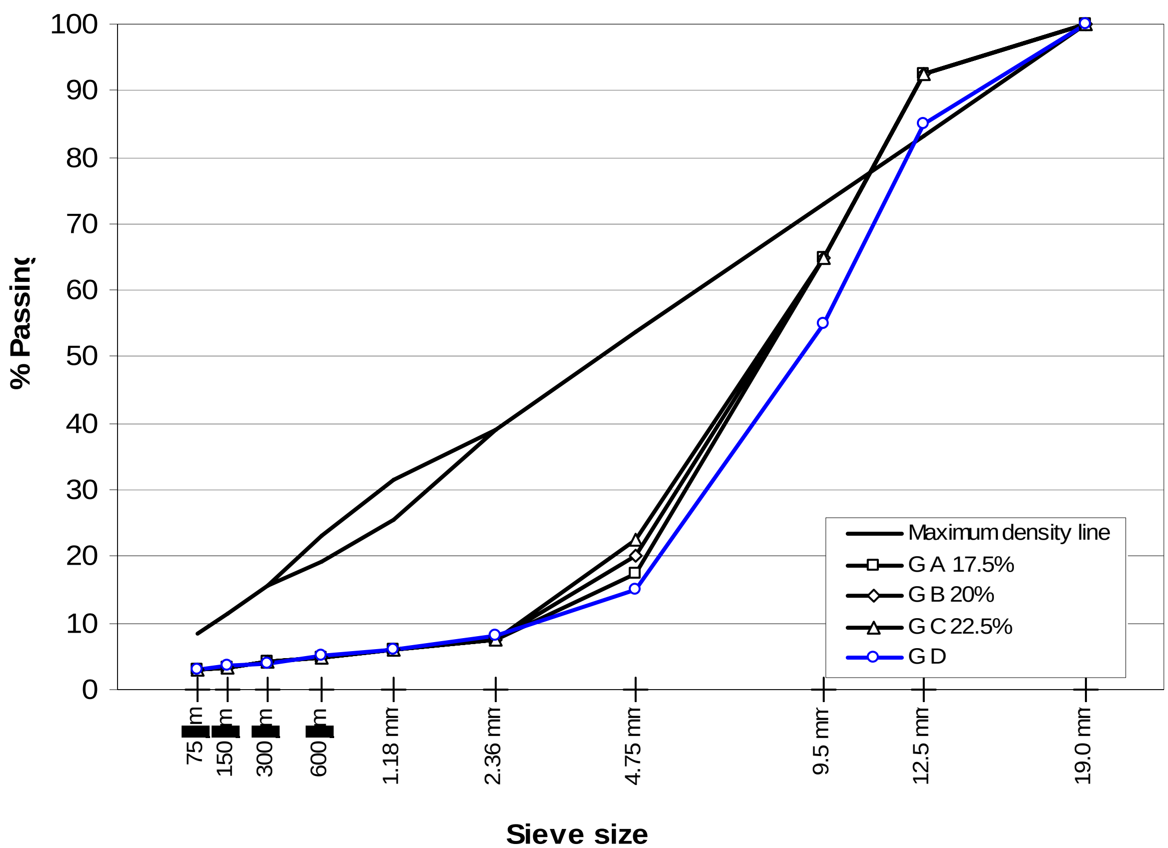

FIGURE 3 Fourth gradation used in the second phase of the study.

TABLE 5 Summary of the mix volumetric properties for the gradations A, B, C and D

	G A			G B			G C			G D		
	No Fibre	0.5% Fibre	2% Lime	No Fibre	0.5% Fibre	2% Lime	No Fibre	0.5% Fibre	2% Lime	No Fibre	0.5% Fibre	2% Lime
Asphalt (%TWA)	6.0	6.0	5.4	5.4	5.5	5.3	5.3	5.8	5.0	5.1	5.6	4.8
Air voids (%)	21.0	21.0	21.0	21.0	21.5	21.0	21.0	21.0	21.0	21.0	21.0	21.0
VMA (%)	30.0	30.7	29.2	29.1	30.2	28.7	29.4	30.0	29.3	28.2	29.6	28.2
VFA (%)	30.3	31.5	27.3	29.5	28.7	27.1	28.6	30.5	28.0	28.0	29.0	25.8
Density (kg/m^3)	1946	1928	1951	1958	1935	1962	1950	1935	1955	1962	1953	1969
Draindown (%)	0.83	0.18	0.06	0.16	0.17	0.04	0.13	0.33	0.03	0.20	0.15	0.06

In these phase of the laboratory study, the mixes were prepared with 2% lime substituting in the filler percentage. It’s important to emphasize that the optimum asphalt content for the four mixes was affected by the lime because in average they were lower than the unmodified mixes and the fiber modified mixes.

Permanent deformation comparison for the four gradations

In order to evaluate the performance of the different mixes, an statistical investigation of the permanent deformation PD APA in mm was made where it be the primary response variable, the first factor was the gradation with four levels GA, GB, GC and GD, the second factor was the additives addition with three levels NF 0.5%F and 2%Lime, the third factor was the temperature with two levels 60 ºC and 70 ºC and the last factor was the number of cycles with two levels 8000 and 16000.

The four factor interaction was analyzed to prove if there weren’t an interaction between the four factors, the results indicated that the principal factors affect the permanent deformation but there were not indication of interaction between the four factors but seemed to be that the triple interaction maybe significant. Table 6 summarized these results.

Based on those findings, the data were separated by cycles into two groups, to determine if the triple interaction between gradation, additives and temperature had a significant effect on the permanent deformation.

TABLE 6 Four way ANOVA results for the permanent deformation data (α = 5%)

Experimental factors	Degrees of Freedom	Sum of Squares	F-Value	P	Significant
Gradation	3	12.831	7.292	0.0001	YES
Additives	2	62.442	53.224	<.0001	YES
Gradation*Additives	6	102.697	29.179	<.0001	YES
Temperature	1	245.692	418.843	<.0001	YES
Gradation*Temperature	3	8.348	4.744	0.0031	NO
Additives*Temperature	2	5.267	4.490	0.0122	NO
Gradation*Additives*Temperature	6	36.662	10.417	<.0001	YES
Cycles	1	63.730	108.644	<.0001	YES
Gradation*Cycles	3	0.482	0.274	0.8443	NO
Additives*Cycles	2	0.475	0.405	0.6673	NO
Gradation*Additives*Cycles	6	2.960	0.841	0.5393	NO
Temperature*Cycles	1	1.801	3.070	0.0810	NO
Gradation*Temperature*Cycles	3	0.906	0.515	0.6725	NO
Additives*Temperature*Cycles	2	0.423	0.361	0.6976	NO
Gradation*Additives*Temperature*Cycles	6	2.934	0.834	0.5450	NO
Error	240	140.783			
C. Total	287	688.433			

For the 8000 cycle group and the 16000 cycle group, the triple interaction remained significant so a Tukey's multiple range test, fixing the temperature, was used to distinguish between means and establish the groupings of different means and equal means.

The permanent deformation of the GA and GB without fiber were significantly different from the others combinations making these mixes very susceptible to permanent deformation for the 60 ºC temperature, but at 70 ºC, G B presented a similar susceptibility to permanent deformation with GC and GD. For the majority of the mixes, the addition of the cellulose fiber reduced the susceptibility to permanent deformation except for GD at 70 ºC and the addition of lime to the mixes presented a large variation making difficult to establish an improvement in the mixes. The results for the two group cycles and all factors are presented in the Figure 4.

Also it could be establish a quality specification of a maximum of 6 mm permitted to this type of mixes. The following mixes didn't meet these criteria: GA NF at 70 ºC with 8000 cycles, GB NF at 60 ºC with 16000 cycles, and GA NF, GB NF, GC 2%Lime, GD NF, GD 0.5%F at 70ºC with 16000 cycles.

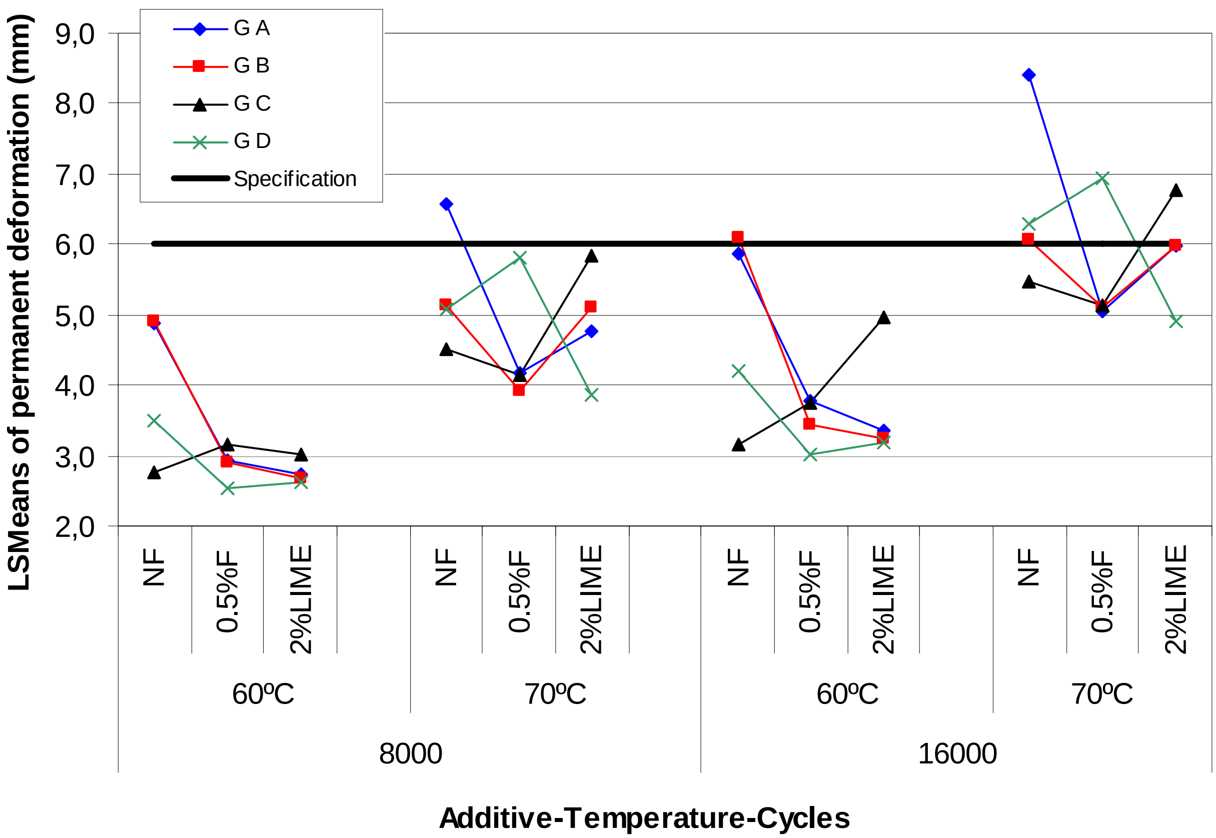

FIGURE 4 Permanent deformation tests for the four gradations, the three additives, two temperatures and two cycles.

Resilient modulus comparison for the four gradations, establishment of the Index of Retained Stiffness (IRS)

The mixes were tested to examine the differences obtain between dry specimens and specimens conditioned at 60 ºC in water for 24 hours. The objective to do this is to establish an Index of Retained Stiffness (IRS), which could distinguish if the mixes are susceptible to water damage during the service life. First, the data were tested to compare the factor conditioned with two levels: non condition and condition so the response variable can be resume to the index.

An statistical investigation of the resilient modulus in MPa was made with it like the primary response variable, the first factor was the gradation with four levels GA, GB, GC and GD, the second factor was the additives addition with three levels NF 0.5%F and 2%Lime, the third factor was the conditioning state with two levels dry and wet and the last factor was the load with two levels 500 N and 1500 N.

The four factor interaction was analyzed to prove if there weren't an interaction between the four factors, the results indicated that the principal factors affect the resilient modulus but there were not indication of interaction between the four factors but seemed to be that the triple interaction maybe significant. Table 7 summarized these results.

Based on those findings, the data were separated by the conditioning state into two groups, to determine if the triple interaction between gradation, additives and conditioning had a significant effect on the resilient modulus.

TABLE 7 Four way ANOVA results for the resilient modulus data (α = 5%)

Experimental factors	Degrees of Freedom	Sum of Squares	F-Value	P	Significant
Gradation	3	2378992	21.6271	<.0001	YES
Additives	2	12515591	170.6664	<.0001	YES
Gradation*Additives	6	8801494	40.0066	<.0001	YES
Conditioning	1	6542550	178.4324	<.0001	YES
Gradation*Conditioning	3	2249072	20.446	<.0001	YES
Additives*Conditioning	2	1551922	21.1625	<.0001	YES
Gradation*Additives*Conditioning	6	4152168	18.8734	<.0001	YES
Load	1	2550035	69.5461	<.0001	YES
Gradation*Load	3	11071	0.1006	0.9596	NO
Additives*Load	2	133412	1.8192	0.1644	NO
Gradation*Additives*Load	6	83220	0.3783	0.8925	NO
Conditioning*Load	1	86251	2.3523	0.1264	NO
Gradation*Conditioning*Load	3	71978	0.6543	0.5809	NO
Additives*Conditioning*Load	2	14263	0.1945	0.8234	NO
Gradation*Additives*Conditioning*Load	6	92814	0.4219	0.8641	NO
Error	240	8800037			
C. Total	287	50034869			

For the dry group and the wet group, the double interaction remained significant so a Tukey´s multiple range test, fixing the load, was used to distinguish between means and establish the groupings of different means and equal means.

The resilient modulus of the GC with the 2% of lime were significantly different from the others combinations making this mix not susceptible to water damage. It's important to mention that the GC without fiber and GD with fiber didn't stand the wet conditioning so these data isn't available for the statistical analysis and it demonstrate that this two mixes are very susceptible to water damage. The results for all factors are summarized in the Figure 5.

After this analysis, it can be establish the new parameter called the Index of Retained Stiffness (IRS) to characterize the susceptibility of the mixes to the water damage, calculated with the next formula:

$$IRS(\%) = \frac{M\,r_{wet}}{M\,r_{dry}} \times 100$$

In summary, the mix with the better IRS is GA without fiber which is contradictory with the standard behavior of these types of mixes. Also the mixes GC without fiber and GD with fiber are already discard to use them in Costa Rica. Finally, with the data it could be establish a minimum IRS for the mixes in 80 % like a quality specification. These results are presented in Figure 6.

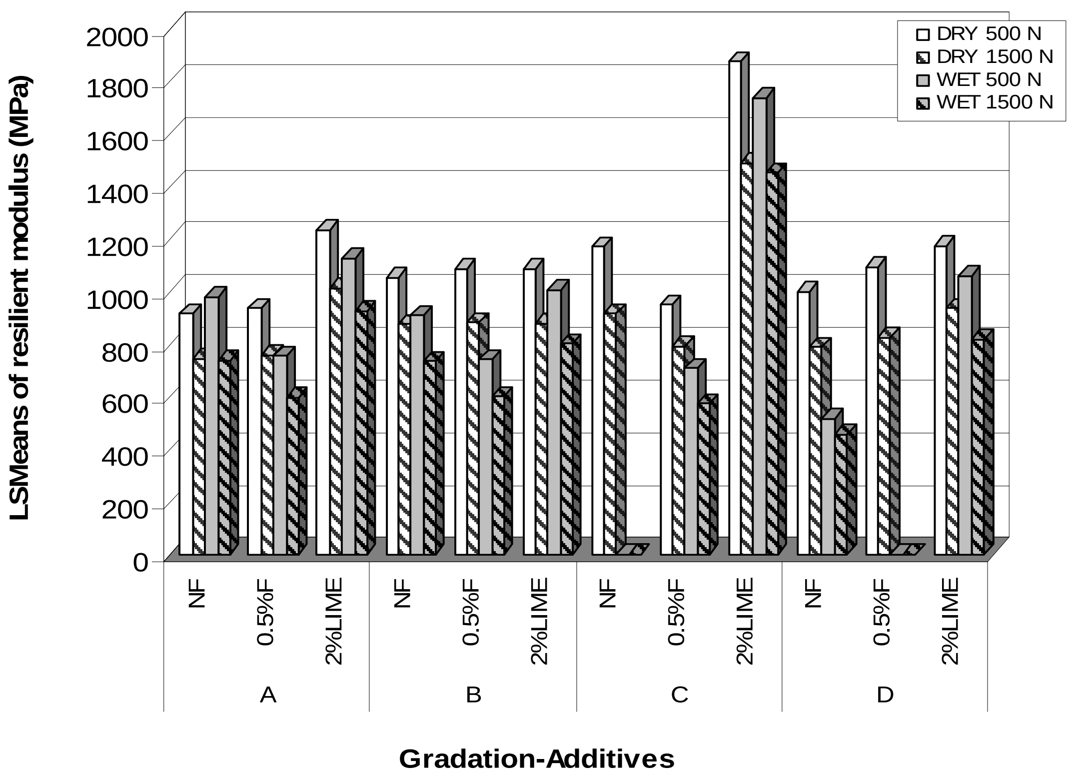

FIGURE 5 Resilient modulus tests for the four gradations, the three additives, two conditionings and two loads.

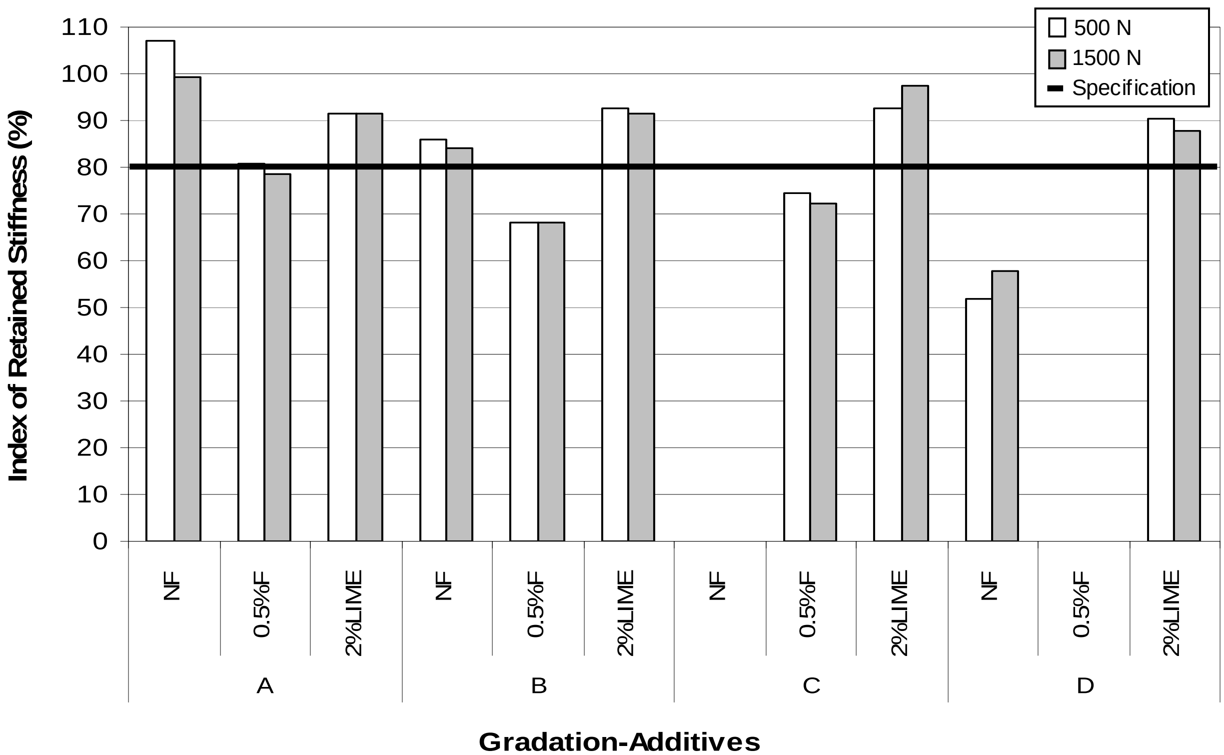

FIGURE 6 Index of Retained Stiffness (IRS) for all mixes and the minimum specification.

SUMMARY AND CONCLUSIONS

The observations and findings drawn from this study are the following:

1. The source of aggregates produce in Costa Rica used in dense graded mixes can be used to produce open graded friction course mixes because it meets the international specifications.

2. A little difference (a maximum of 1.2%) exists on the optimum asphalt content for the four gradations, the VMA remains almost constant also the VFA. The 0.5% of fiber affects the density by reducing it an average of 16 kg/m^3. The asphalt contents of the OGFC's mixes are similar to those used in the production of the dense mixes. The only mix susceptible to draindown is G A without fiber but the addition of the cellulose fiber improves the percentage of draindown.

3. The susceptibility to permanent deformation of the mixes did appear to be statistically significant influenced by the mix composition and the environmental conditions like the temperature and the load repetitions. The mix with the higher permanent deformation was GA without fiber so this is related to the higher presence of "loose" binder, reflect in the draindown test.

4. A quality specification for the permanent deformation may be 6.0 mm which is the maximum allowable because after the statistical analysis, the mixes presented higher deformations for the higher number of cycles, with the consequent lose of service life with the increase of load numbers causing the maintenance costs to increase.

5. The addition of the cellulose fiber to the mixes did improve the susceptibility to permanent deformation of the majority of the mixes studied reflect in the lesser variability of the data, with the exception of GD at 70 ºC.

6. A significant difference was observed on the mix GC with 2% lime in the resilient modulus tests compare to the others mixes, but these effect of the lime wasn’t significant to the others mixes.

7. The addition of the cellulose fiber effect significantly the stiffness of the mixes reflected directly on the observed Index of Retained Stiffness (IRS) where mixes which stand the period of conditioning had lower IRS. These effects are given by the affinity of the cellulose fiber to water increasing the susceptibility of the mix to the effect of the climate conditions.

8. The conditioning phase on the mixes was statistically significant on the modulus; these results are good indicators of the susceptibility to water damage of the mixes reflect on the index IRS, which permit to establish it in a quality specification with a minimum of 80%.

RECOMMENDATIONS

Based on the findings of the research project, the recommendations are the following:

1. The addition of different sources of aggregates is warranted to prove that in Costa Rica other zones can use these types of mixes to improve the safety, like the South Coast Highway which connect to Panama in the southeast of the country or the Inter-American Highway to Nicaragua in the northwest. Also with the objective of establish the quality specifications for the aggregates used to produce hot mix asphalt.

2. The use of modified asphalt in this mix is important to get a good modulus so it’s important that the asphalt producer in Costa Rica consider to expand its market and began to produce modified binders.

3. Perform a field study to establish a correlation between the permanent deformation measured with the APA and the lost of voids in the OGFC’s mixes, in order to predict the service life and the program of maintenance.

4. Finally, the mixes recommended to use in the Costa Rican highways are: GA – GB without fiber even they presented a large permanent deformation, and the better ones were GA – GB – GC – GD with 2% of lime but the better one is GC which presented the higher modulus.

REFERENCES

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