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OPEN-GRADED FRICTION COURSE: STATE OF THE PRACTICE

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FOREWORD

This circular summarizes the results of a survey conducted by the National Center for Asphalt Technology (NCAT). Prithvi S. Kandhal and Rajib B. Mallick were the investigators on the project. It is published in this Circular because Transportation Research Board Committee A2D03, Characteristics of Bituminous-Aggregate Combinations to Meet Surface Requirements, reviewed the information and determined it provides up-to-date information on the use of open-graded friction courses (OGFC) for applications where providing a high level of surface friction is important for the safety of the motoring public. The committee recommended wide distribution of this information by TRB. This Circular describes the current state-of-the-practice and should be of interest to pavement designers and others responsible for selecting the materials to be used in particular roadway applications.

INTRODUCTION

Open-graded friction courses (OGFCs) have been used since 1950 in different parts of the United States to improve the frictional resistance of asphalt pavements. However, the experience of states with this kind of mix has been widely varied. While many states have reported good performance, many other states have stopped using OGFC due to poor performance (1). However, many improvements have been made during the last few years in the way OGFCs are designed and constructed. A survey of state highway agencies was needed to determine where OGFCs have been used, why they are used in some states and not in others, mix design and construction practices, OGFCs' performance history, and problems encountered. Results of such a survey can be used to correlate performance of OGFCs to design parameters and construction practices, and potential changes could be identified to improve the performance of OGFCs.

OBJECTIVE

The objective of this report is to present the results of a survey carried out by the National Center for Asphalt Technology (NCAT) on design and construction practices for OGFCs.

SURVEY PLAN

A questionnaire on the design and performance experience related to OGFCs was sent out to highway agencies in 50 states. Responses to the questionnaire were received from 43 states. The responses obtained from this survey were compiled in a database, which was analyzed to obtain specific information about the current state of practice of OGFC.

RESULTS OF SURVEY

A large number of states reported good performance of OGFC, whereas many states reported poor performance, and a few states indicated no experience with OGFC. The states that reported poor performance had stopped using OGFC. The results of the survey are presented according to the specific questions asked to the highway agencies.

Use of OGFC

Figure 1 indicates the percentages of states surveyed that use OGFC, that used it in the past, or that have never used it. Eight percent of the states have never used OGFC, 38 percent of the states use it at present, whereas 38 percent of the states have stopped using OGFC because of unfavorable experience. Sixteen percent of the states did not respond to the questionnaire. If it can be demonstrated that the performance of OGFCs can significantly be improved through the use of polymer-modified asphalt binders and improved mix design procedures, there is a potential that the 46 percent of the states that do not use OGFC at the present time will start using it. Survey results of state experience for specific questions about OGFC are presented in the following sections. The percentages indicated in each of the plots are based on the number of states that responded to the specific question.

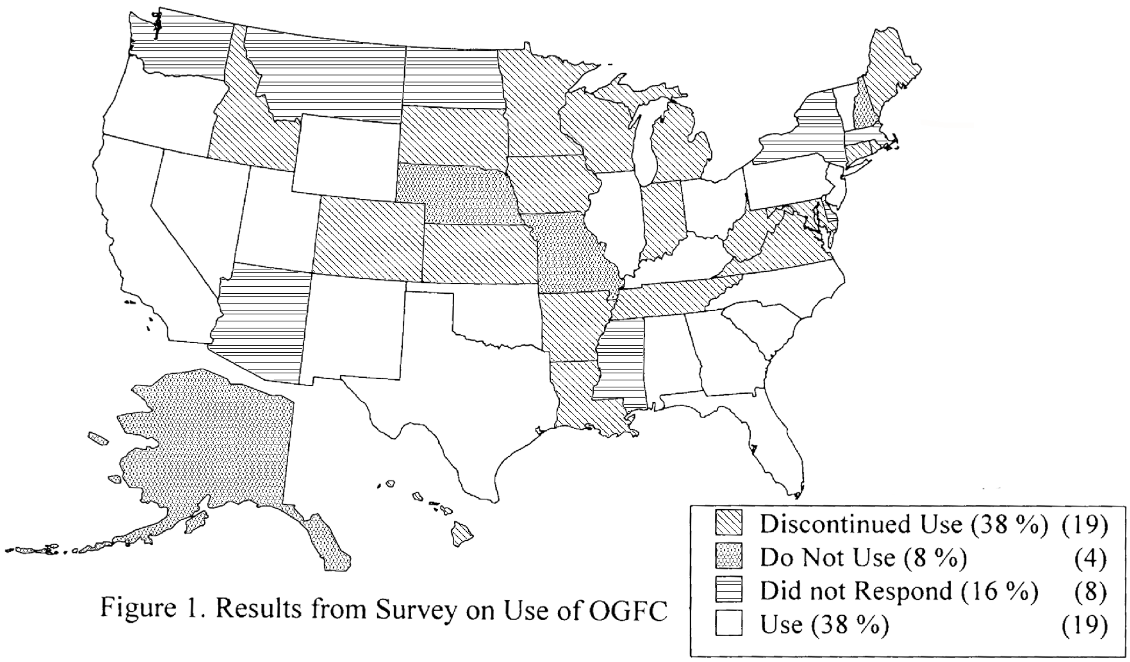

Figure 1. Results from Survey on Use of OGFC

Estimated Average Service Life of OGFC

Reported average service life of OGFC in different states is presented in Figure 2. Seventeen percent of the states reported an average service life of less than 6 years, 10 percent reported 6-8 years, 30 percent reported 8-10 years, 33 percent reported 10-12 years, whereas 10 percent reported more than 12 years. Since 43 percent of states have obtained an average service life of more than 10 years, OGFCs can be designed and constructed successfully.

Performance of OGFC

Performance of OGFC in terms of durability and surface friction was reported by highway agencies in different states on scales of poor to excellent ratings. As shown in Figure 3, in terms of durability, 11 percent of the states surveyed reported poor performance, 11 percent reported fair performance, 37 percent reported good performance, and 37 percent reported very good performance, whereas 4 percent indicated that they have observed excellent performance of OGFC. Figure 3 is very similar to Figure 2, which shows the average service life of OGFCs. Figure 4 shows that in terms of surface friction, none of the states that used or use OGFC reported poor performance, 4 percent reported fair performance, 11 percent reported good performance, and 55 percent reported very good performance, whereas 30 percent stated that they have observed excellent performance of OGFC. This indicates that OGFCs have generally given good surface frictional properties as intended.

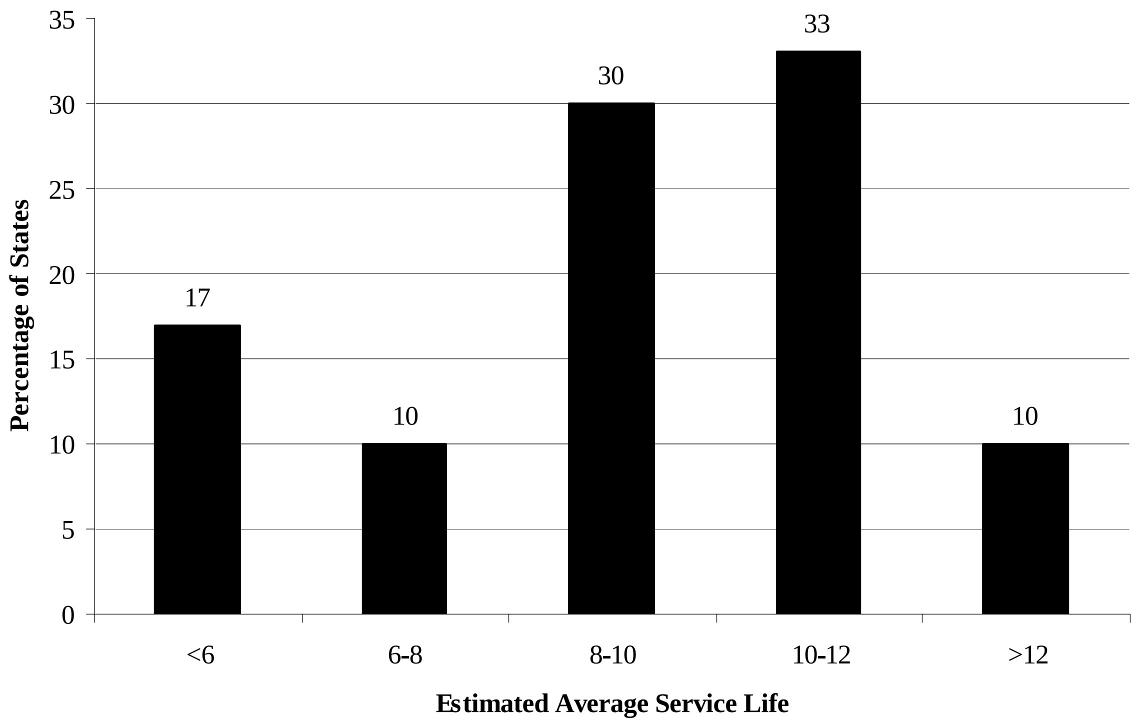

FIGURE 2. ESTIMATED AVERAGE SERVICE LIFE OF OGFC

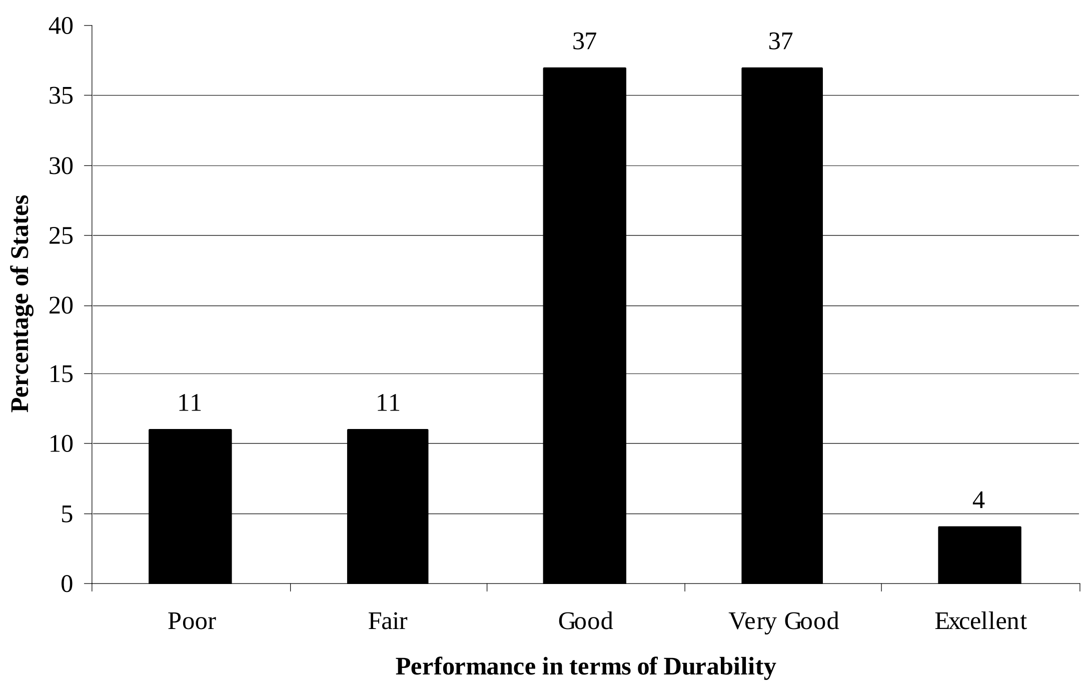

FIGURE 3. PERFORMANCE OF OGFC IN TERMS OF DURABILITY

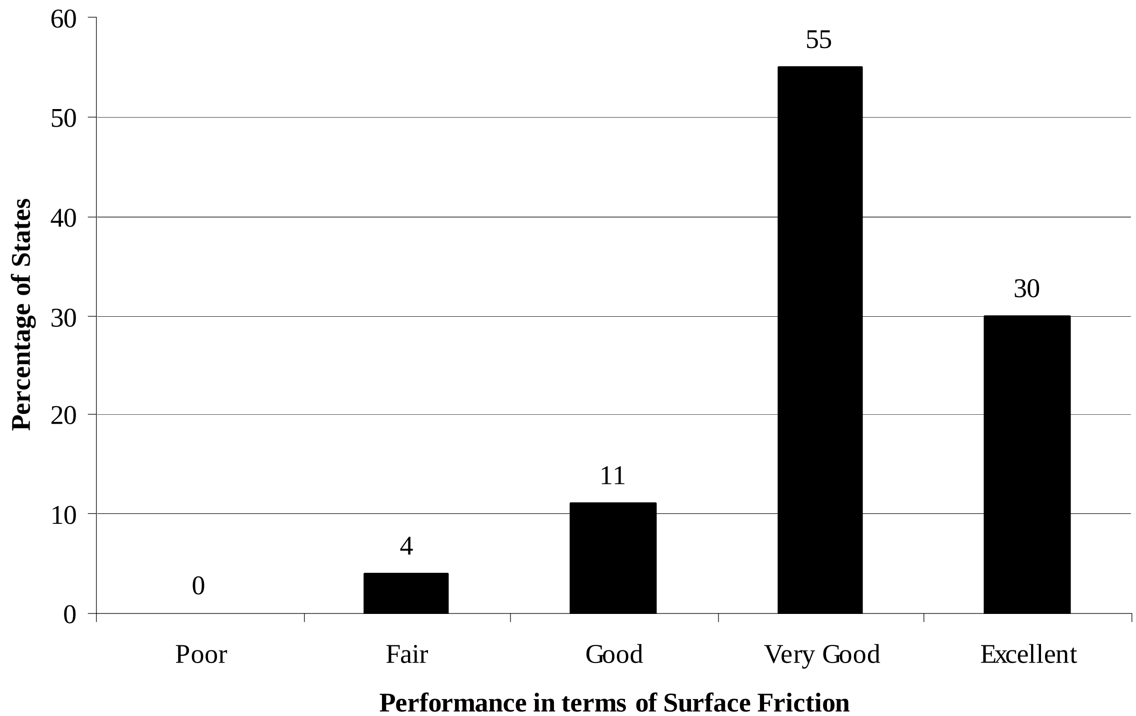

FIGURE 4. PERFORMANCE OF OGFC IN TERMS OF SURFACE FRICTION

Traffic

The results from the survey on traffic levels for OGFC pavements are shown in Figure 5. Unfortunately, high, medium and low traffic were not properly defined in the questionnaire.

Twenty-nine percent of the states reported that they use OGFC on low-traffic roads, 63 percent reported use on medium-traffic roads, and 75 percent reported use on high-volume roads. Twenty-nine percent of the states do not have any restriction on the use of OGFC regarding traffic level. The total percentage exceeds 100 since many states use OGFC in both low- and medium- or both medium- and high-traffic roads.

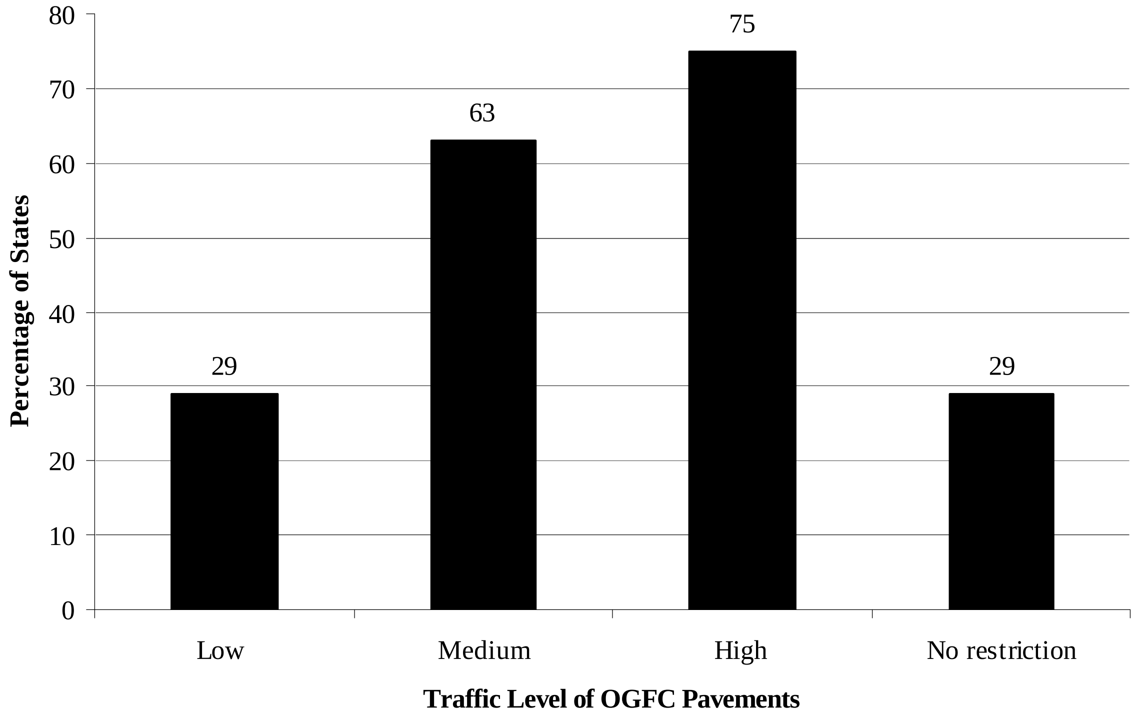

FIGURE 5. TRAFFIC LEVEL OF PAVEMENTS ON WHICH OGFC IS USED

Specification of OGFC

Figure 6 shows that 76 percent of the states specify OGFCs through standard specifications, whereas 7 percent of the states use special provisions. Seventeen percent of the states do not have any specification or special provision. These percentages are based on states that use OGFC at present or that used OGFC in the past but do not use it at present.

Mix Design of OGFC

The survey included several questions about materials and mix design procedures for OGFCs. Figure 7 shows that 76 percent of the states indicated that they have formal mix design

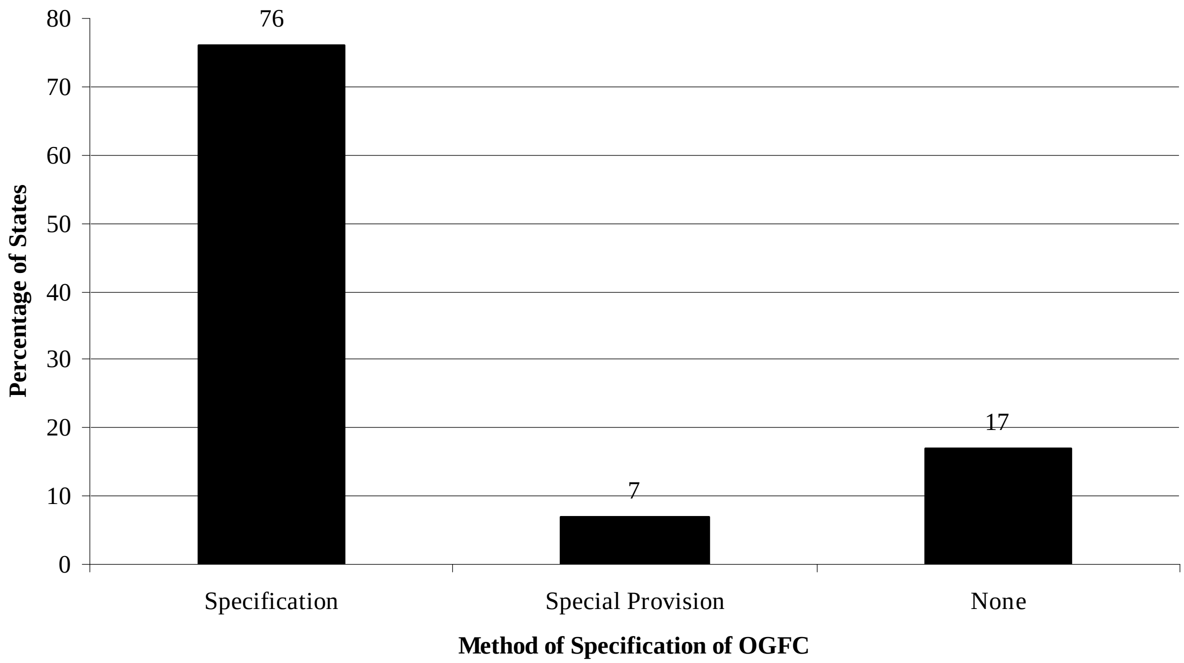

FIGURE 6. METHOD OF SPECIFICATION OF OGFC MIXES

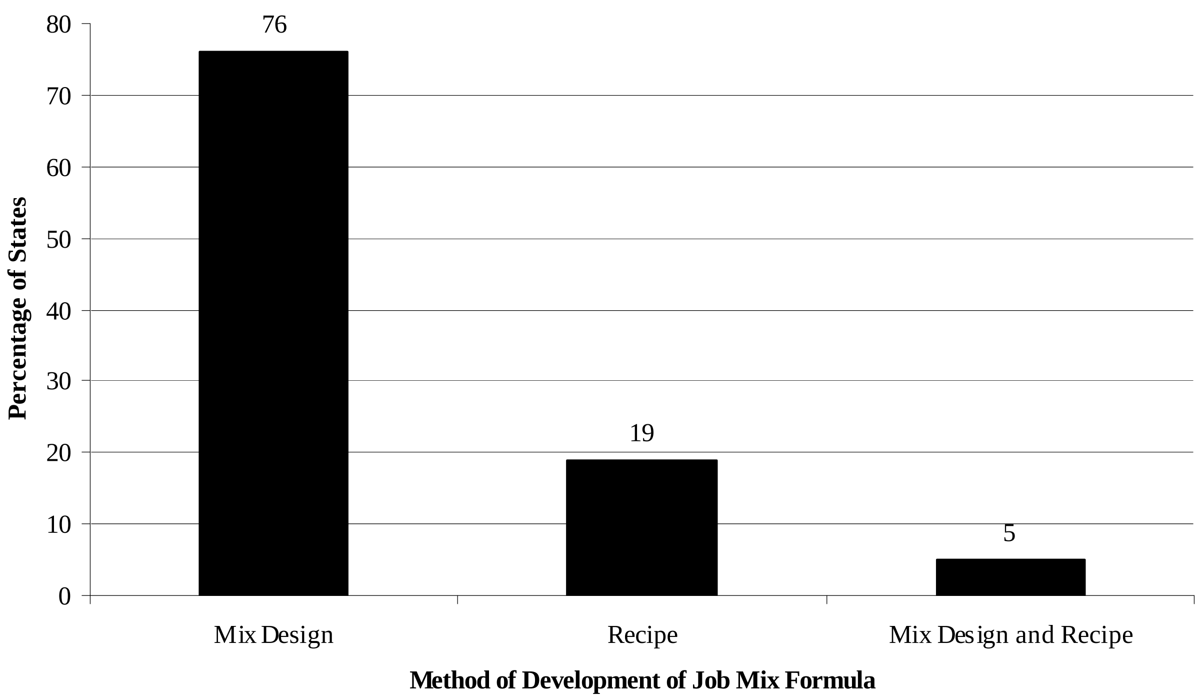

FIGURE 7. METHOD OF DEVELOPMENT OF JOB MIX FORMULA

procedures for OGFC, and 19 percent of the states reported that they use recipe specifications. Five percent of the states use a combination of the mix design and the recipe method. As indicated in Figure 8, 42 percent of the states specify a range of asphalt content, whereas 58 percent do not. The different aggregate gradation ranges are shown in Table 1. Figure 9 shows that 26 percent of the states follow the FHWA procedure (2) to establish mix temperature to prevent draindown of asphalt binder, 37 percent of the states use other draindown tests, whereas 37 percent of the states do not use any test, but use temperatures from viscosity-temperature charts for specific binders. Table 2 shows the different grades of asphalt binders used by the state transportation agencies. Figure 10 shows that 48 percent of the states use polymer-modified binders, while 52 percent do not. However, these percentages are based on total number of states surveyed, including those that do not use OGFC at present. As indicated in Figure 11, 46 percent of the states use cellulose fiber, hydrated lime, or some form of antistrip agents, whereas 54 percent of the states do not use any additive other than modifier for binder. Figure 12 shows that 19 percent of the states using additives use fiber, 13 percent use silicone, 13 percent use crumb rubber, 31 percent use liquid antistrip agent, and 44 percent use hydrated lime. The percentages total more than 100 percent because some states use more than one additive.

A wide divergence in the mix design practices across the U.S. has probably contributed to the variable success rate. A standard mix design procedure needs to be developed to assure a good success rate in all states.

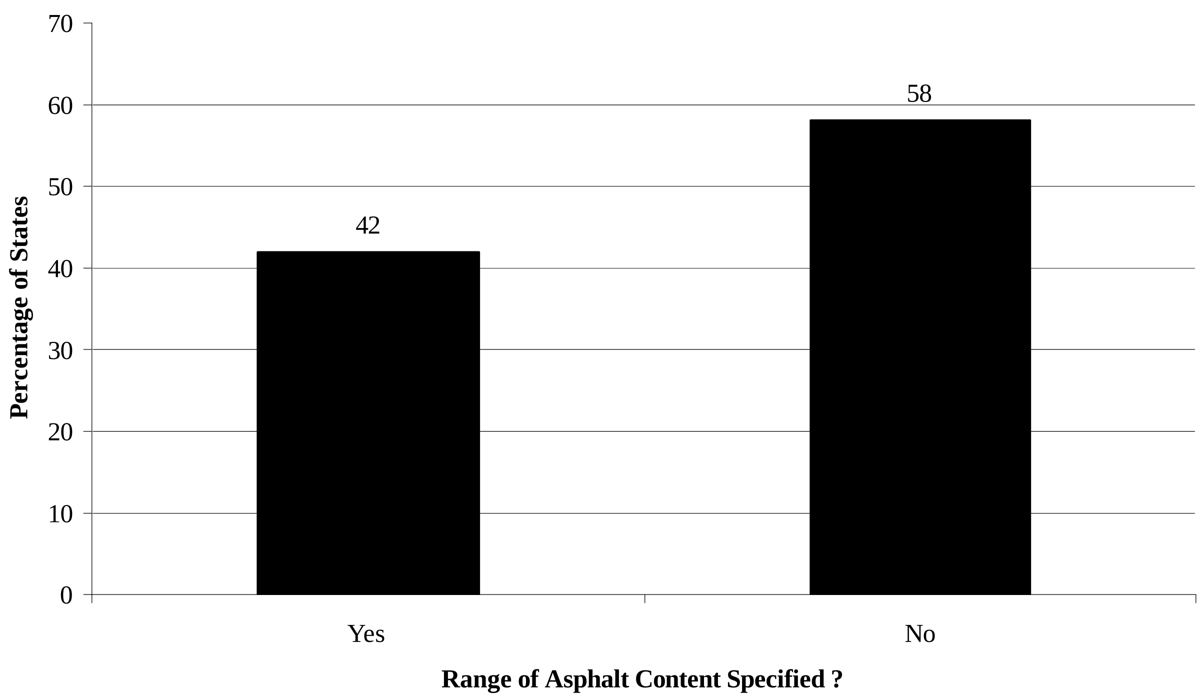

FIGURE 8. PERCENTAGES OF STATES THAT SPECIFY RANGE OF ASPHALT CONTENT OF OGFC

TABLE 1. GRADATION OF OGFC MIXES IN DIFFERENT STATES.

State	Percent Passing Sieve (mm)												
	25	19	12.5	9.5	6.3	4.75	2.36	2	1.18	0.6	0.3	0.15	0.075
AL			100	90-100		30-50	5-7						3-6
		100	90-100	40-70		5-30	4-12						3-6
CA				78-89		28-37	7-18						
CO			100	90-100		35-57	12-33				3-15		2-8
			100	90-100		40-60	20-47				4-18		2-9
FL			100	85-100		10-40	4-12						2-5
GA		100	85-100	55-75		15-25	5-10						2-4
HI				100		30-50	5-15						2-5
ID		100	95-100	30-80		35-46				8-15			2-5
IL		100	90-100	30-50		10-18							2-5
KY			100	90-100		25-50	5-15						2-5
LA		100	90-100	30-50		10-30		5-20					2-6
				90-100		20-50	5-15						2-6
MD			100	90-100		20-40	5-15						0-5
MI			100	90-100		30-50	8-15						2-5
NV			100	90-100		35-55			5-18				0-3
				95-100		40-65			12-22				0-4
NJ			100	80-100		30-50	5-15						2-5
NM			100	90-100		25-55	0-12						0-4
NC			100	75-100		25-50	5-15						1-3
		100	85-100	55-75		15-25	5-10						2-4
OH			100	85-96		28-45	9-17						2-5
OR		99-100	90-98		25-40		2-12						1-5
	99-100	85-96	55-71		15-30		5-15						1-6
PA				100		30-50	5-15						0-5
RI		90-100				20-50	5-15						2-5
SC			100	98-100		40-70	2-20						0-2
TX		100	95-100	50-80		0-8	0-4						
UT			100	92-100		36-44	14-20						2-4
VT			100	95-100		30-50	5-15						2-5
WY			100	97-100		25-45	10-25						2-7
			100	97-100		20-40	10-20						2-7

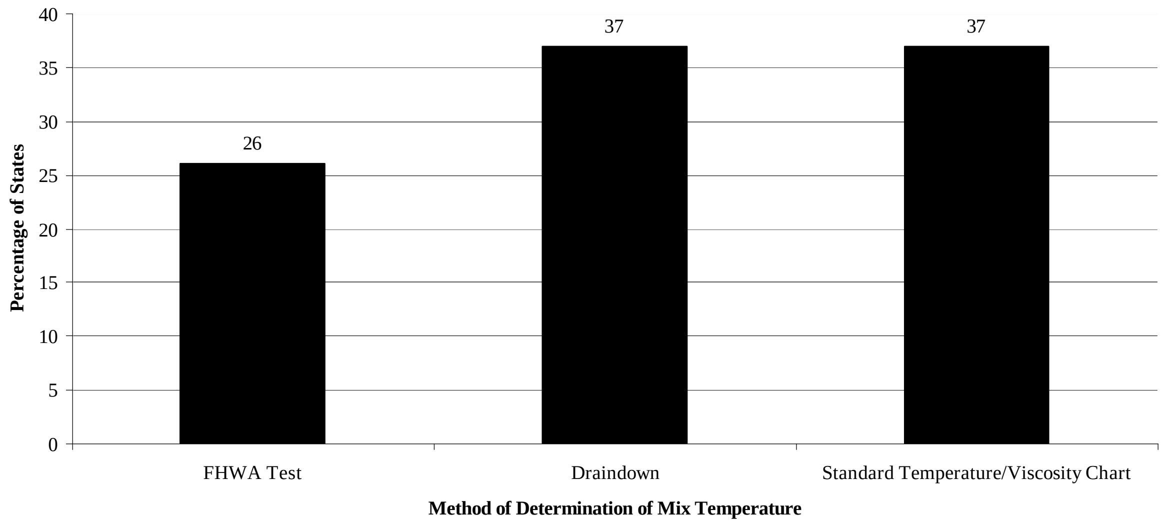

FIGURE 9. METHOD OF DETERMINATION OF MIX TEMPERATURE TO PREVENT EXCESSIVE DRAINDOWN

TABLE 2. ASPHALT BINDERS USED FOR OGFCs.

State	Asphalt Binder
AL	PG 76-22
CA	AR 2000, 4000, 8000
CO	AC 20R
FL	AC 30
GA	PG 76-22
HI	AR 80
ID	--
IL	AC 10
KY	PG 64-22
LA	PG 70-22
MD	AC 20
MI	---
NV	AC 20P, AC 30
NJ	AC 20
NM	---
NC	AC 20P
OH	AC 20
OR	PBA 5, PBA 6
PA	AC 20
RI	AC 20
SC	PG 64-22
TX	AC 20, AC 10
UT	PG 64-34
VT	AC 20
WY	AC 20, AC 10

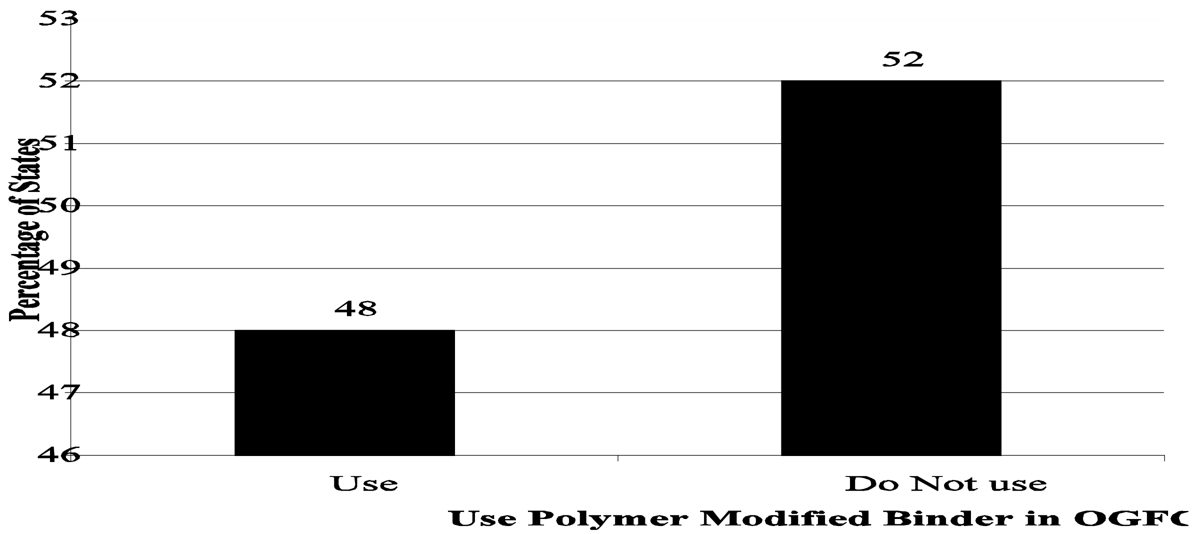

FIGURE 10. USE OF POLYMER-MODIFIED BINDER IN OGFC

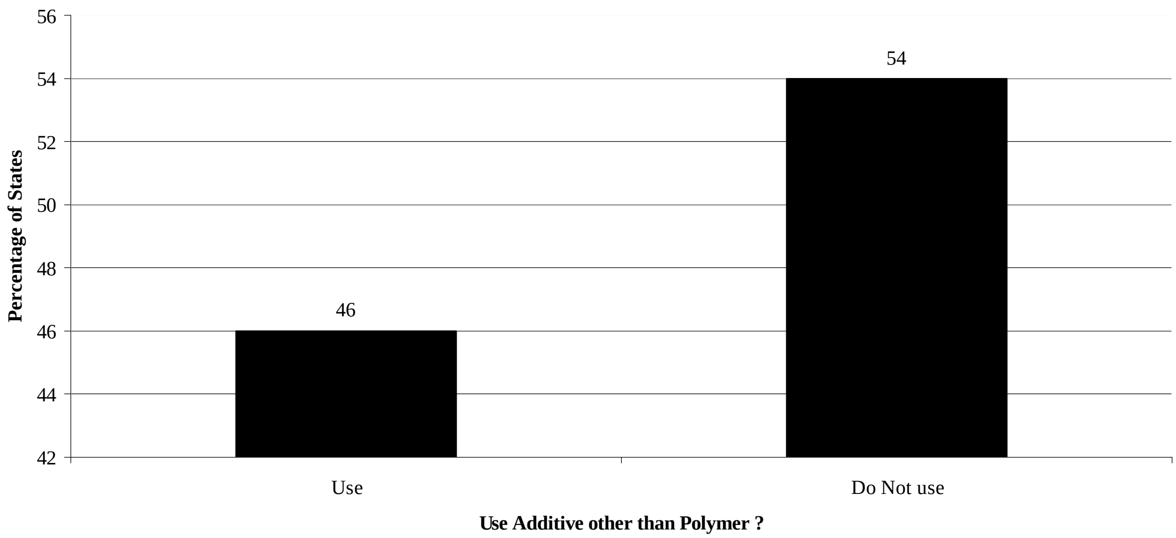

FIGURE 11. USE OF ADDITIVE OTHER THAN POLYMER

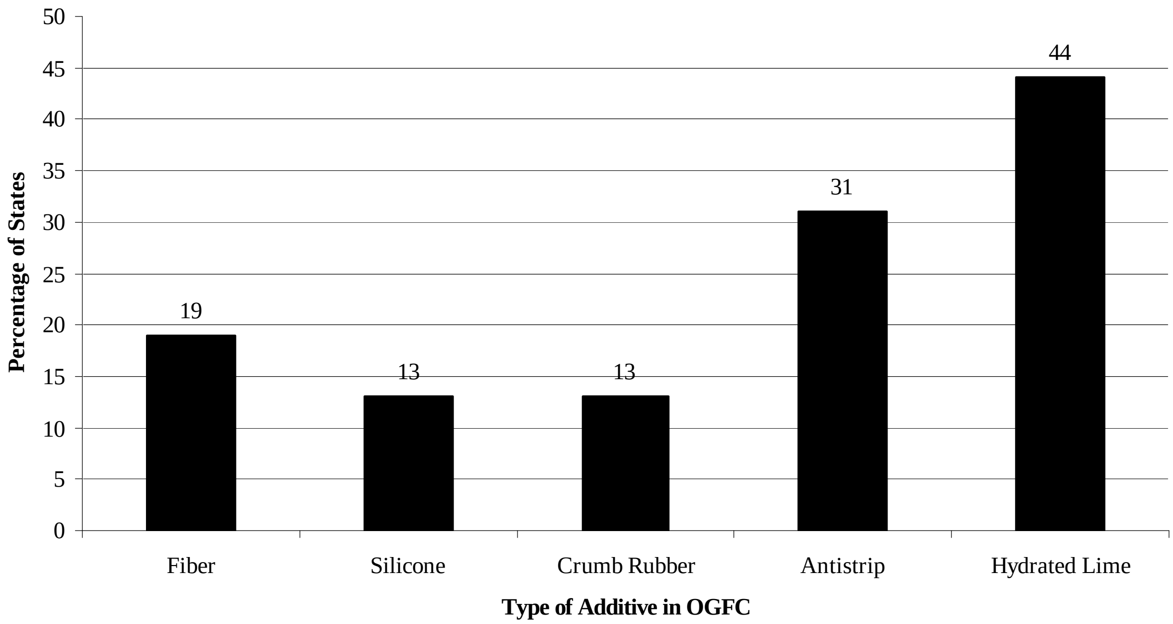

FIGURE 12. TYPE OF ADDITIVE OTHER THAN POLYMER IN OGFC

Construction

Most of the states specify the use of some kind of tack coat before construction of open-graded friction course. As shown in Figure 13, 88 percent of the states surveyed use emulsion, whereas only 8 percent use asphalt cement as tack coat material. Eight percent of the states surveyed do not use any kind of tack coat. The percentages total more than 100 because some states specify both emulsion and asphalt cement as tack coat material. Figure 14 shows that equal percentages (23) of states specify 0.1-0.2, 0.2-0.3, 0.3-0.4, or 0.4-0.5 liter per sq. m, whereas 8 percent of the states specify an application rate of less than 0.1 liter per sq. m. Figure 15 and 16, respectively, show the minimum specified surface and air temperature for OGFC paving. Nine percent of the states specify a minimum air temperature of 10EC, 45 percent specify 15EC, 32 percent specify 21EC, and 14 percent do not have any specification. Twelve percent of the states specify a minimum surface temperature of 9EC, 35 percent specify 15EC, 6 percent specify 21EC, and 47 percent do not specify any minimum surface temperature. Figure 17 shows that 5 percent of the states specify in-place voids criteria for compaction (for example, Alabama specifies 15-20 percent air voids in the mat after compaction), 80 percent of the states specify roller weight and/or roller passes, whereas 15 percent do not have any specific compaction criteria. As indicated in Figure 18, 86 percent of the states place OGFC on new asphalt overlay in the same year, 5 percent place it after 1 year, whereas 9 percent of the states do not have any specific time period.

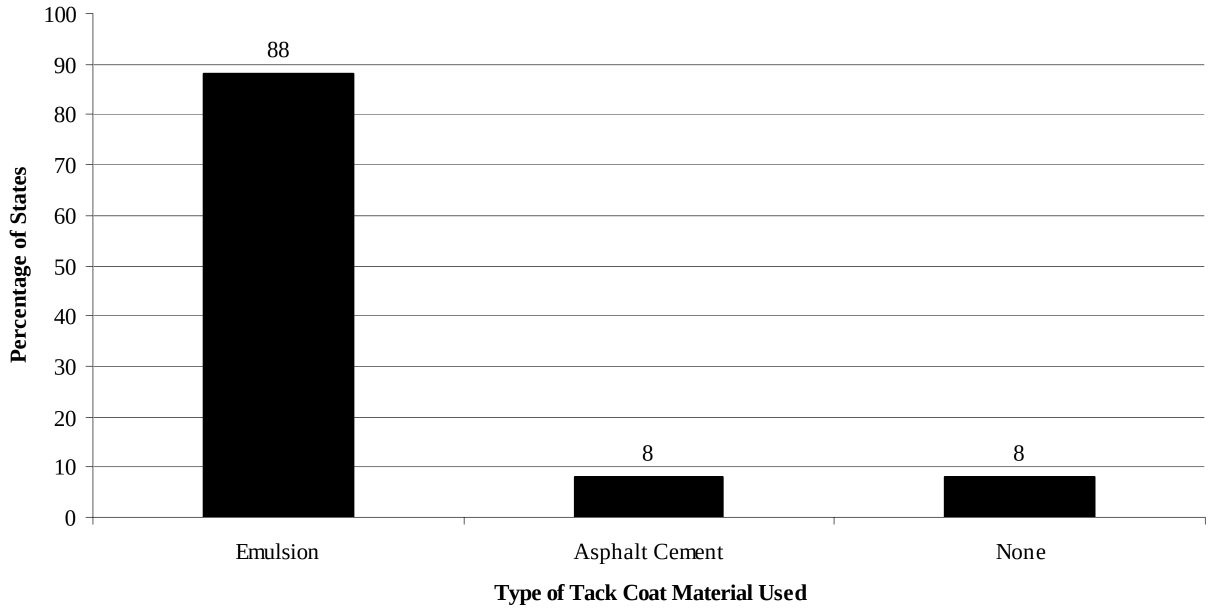

FIGURE 13. TYPE OF TACK COAT MATERIAL USED IN OGFC

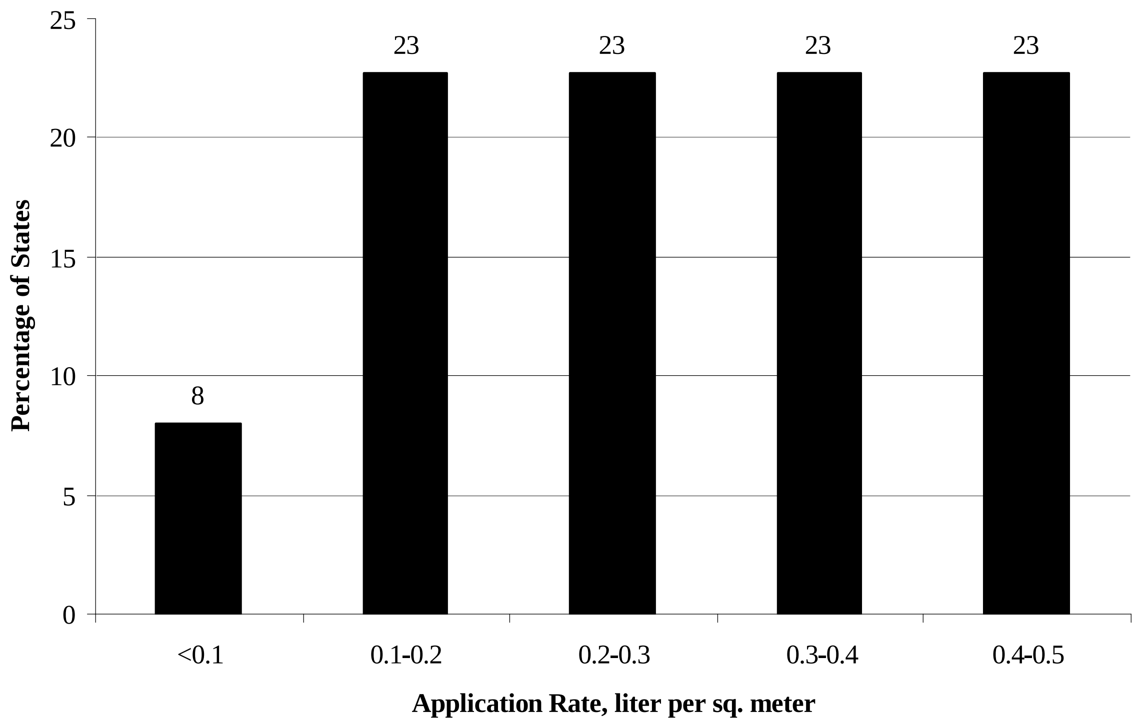

FIGURE 14. APPLICATION RATE OF TACK COAT MATERIAL

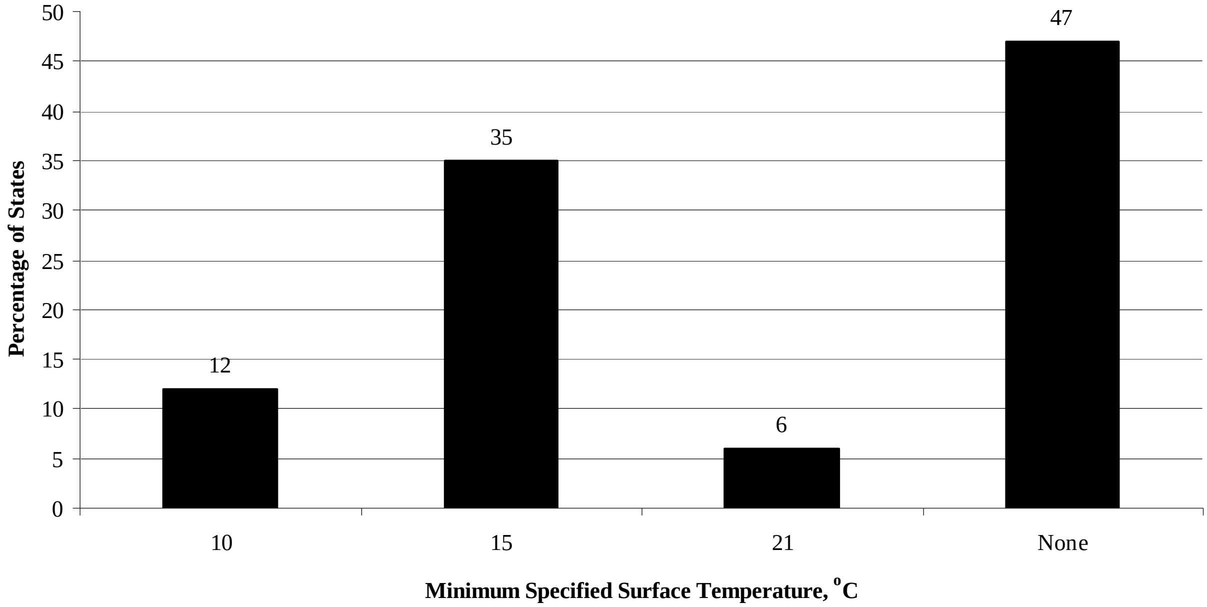

FIGURE15. MINIMUM SPECIFIED SURFACE TEMPERATURE FOR CONSTRUCTION OF OGFC

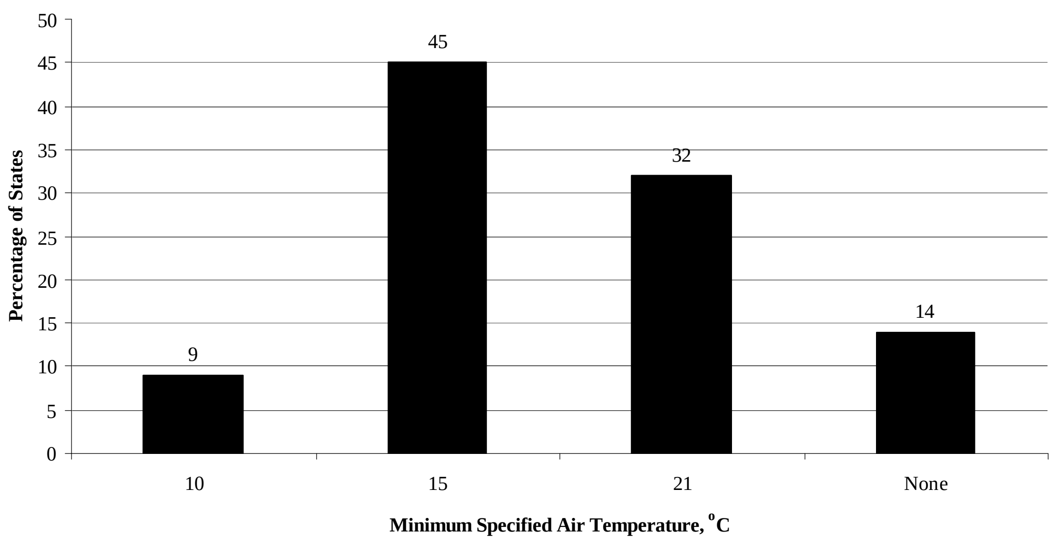

FIGURE 16. MINIMUM SPECIFIED AIR TEMPERATURE FOR CONSTRUCTION OF OGFC

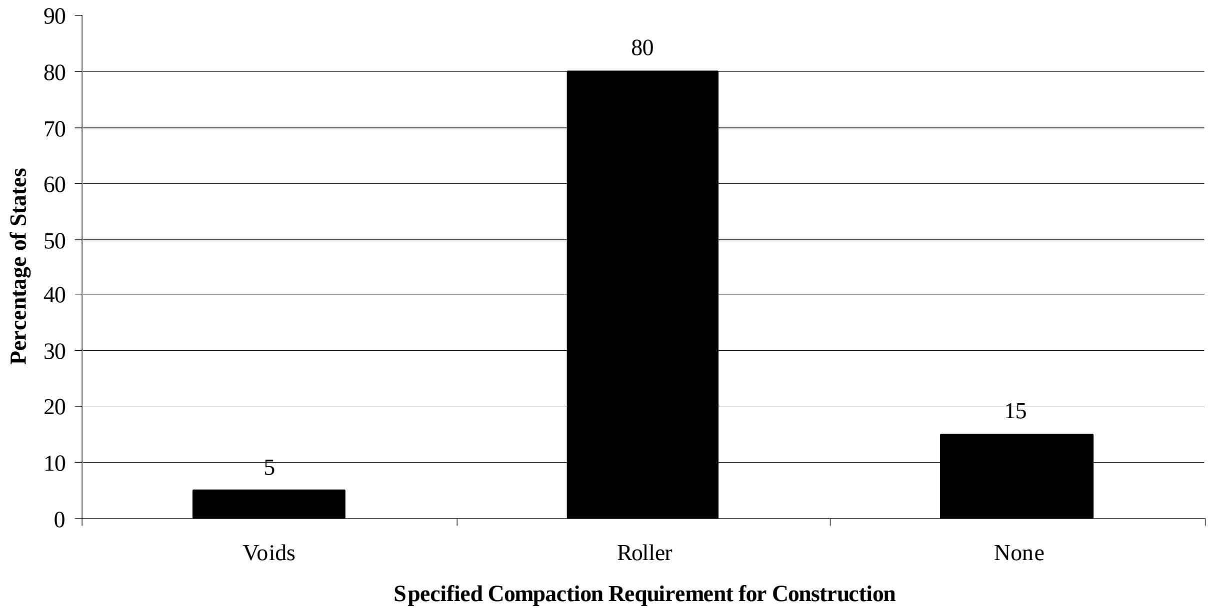

FIGURE 17. SPECIFIED COMPACTION REQUIREMENT FOR CONSTRUCTION OF OGFC

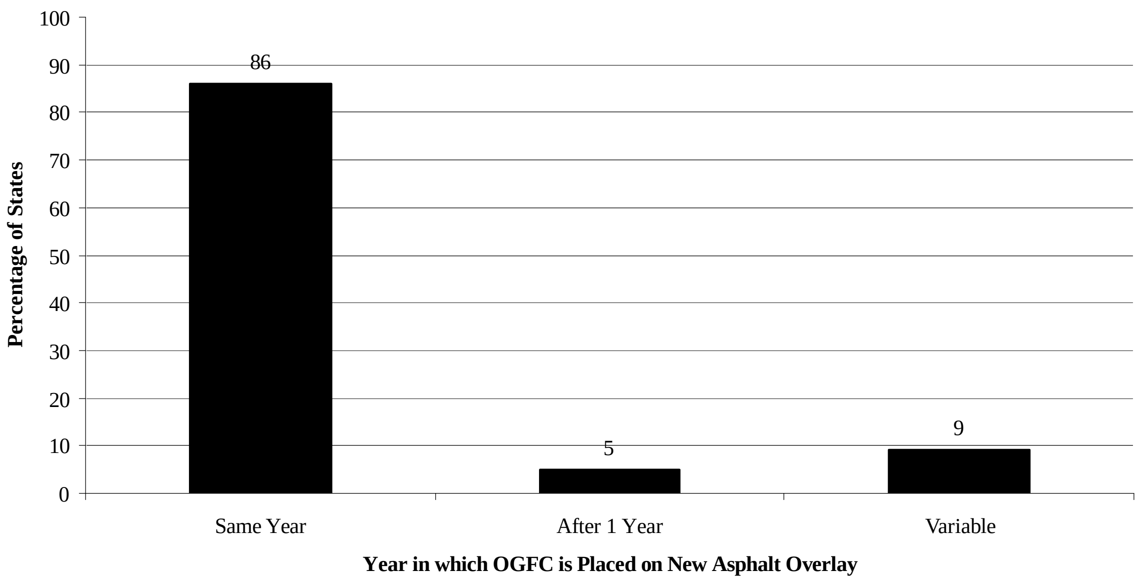

FIGURE 18. YEAR IN WHICH OGFC IS PLACED ON NEW ASPHALT OVERLAY

DISCUSSION OF RESULTS

To draw meaningful conclusions from the survey, the states were classified according to Strategic Highway Research Program (SHRP) climatic zone criteria into four groups: Wet-Freeze, Wet-No Freeze, Dry-Freeze, and Dry-No Freeze. Table 3 shows specific problems reported by some states in these four zones. In the Wet-Freeze zone the main problem seems to be raveling and stripping of underlying layers. Problems not related to mix performance include difficulty in removal of snow and clogging up of voids by ice control materials such as sand and reduced permeability (3). In the Dry-Freeze zone, the main problem seems to be removal of snow and closing up of voids by sand, although one state reported stripping in underlying layers. In the Wet-No Freeze zone, the problems include raveling of OGFC, stripping of underlying layers, and closing up of voids. In the Dry-No Freeze zone, the only reported problem is raveling of OGFC due to absorptive aggregate.

To study the differences in mix design of OGFC between states that have good experience and states that have bad experience with OGFC, three mix design items were listed for each state, as shown in Table 4. In the Wet-Freeze zone, most of the states that have good experience and do use OGFC at present use polymer-modified binders, whereas those that had bad experience and have stopped using OGFC did not use polymers. The percent passing the 2.36 mm sieve (percentage of fines) seems to range between 5 and 15 for most of the states. Also, there is not much difference in the use of other additives between states having good and bad experience.

In the Dry-Freeze zone, all of the states that have good experience use hydrated lime, whereas three out of four states that have bad experience do not. The percentage passing the 2.36 mm sieve seems to be higher for states in this zone (about 10-30). Again, the most prominent difference seems to be in the use of polymer-modified binders: all of the states with good experience use polymer, whereas three out of four states that have bad experience did not use polymer.

In the Wet-No Freeze zone, most of the states with good experience use polymers, and half of them use some other additive such as rubber or fiber. However, most of the states with bad experience did not use polymer or other additive. The percentage passing the 2.36 mm sieve of the one state with bad experience for which gradation is available seems to be higher than the percentage passing the 2.36 mm sieve for the states with good experience.

For the Dry-No Freeze zone, all of the states with good experience use polymers, and most of them use other additives. The only state with bad experience did not use polymer, but used silicone as an additive. There is no distinct difference between the percentage passing the 2.36 mm sieve for the states with good and the state with bad experience with OGFC.

The survey on the use of OGFC revealed that the primary mix performance problems are raveling of OGFC and stripping of underlying layers. The raveling of OGFC seems to be a problem with the loss of bond (cohesion) between the aggregate particles. The stripping of the underlying layers can be attributed to inadequate drainage of water through the OGFC. Therefore, two of the most important features of OGFC mix are air voids and bonding of aggregates. The drainage capacity of an OGFC is a direct function of the air voids. European experience shows that excellent OGFC mixes can be obtained by using voids in the range of 20-25 percent. Air voids in U.S. OGFC mixes have been generally in the range of 10-15 percent in the past, probably because of the draindown potential of asphalt binder in coarse, high air void content mixes.

TABLE 3. PROBLEMS WITH OGFC.

Zone: Wet-Freeze

State	Problem
IA	Removal of ice very difficult.[1]
MD	Raveling in OGFC.
ME	Removal of ice very difficult[1].
MN	Deicing sand clogged voids[1]; stripping of OGFC.
RI	Durability problem; widespread debonding; OGFC scraped by snowplows.
VA	Stripping in underlying layers; needed heavy fog coat after several years to prevent raveling.

Zone: Wet-No Freeze

State	Problem
AK	Filling up of voids, leading to moisture retention, prolonged freezing, and snow and ice removal problems.
LA	Extensive raveling.
TN	Stripping in underlying layers; aggregate loss in OGFC by raveling; snow and ice removal problem due to re-freezing of melted snow and ice[1].

Zone: Dry-Freeze

State	Problem
CO	Moisture damage to underlying layers.
ID	Sanding caused filling up of voids[1].
KS	During winter snow and ice storm, voids became filled with water and froze; developed icy surface; took substantially higher amount of salt to melt ice[1].
SD	Sand and salt plugged up the voids[1].

Zone: Dry-No Freeze

State	Problem
HI	Raveling because of absorptive aggregate.

Note: [1]: Problems not related to performance

TABLE 4. MIX DESIGN PRACTICES OF STATES WITH GOOD AND BAD EXPERIENCES.

Zone: Wet-Freeze

Good Experience				Bad Experience			
State	Use Polymer	Use Other Additive	Percent Passing 2.36 mm Sieve	State	Use Polymer	Use Other Additive	Percent Passing 2.36 mm Sieve
IL	Yes	No	---	IA	No	No	---
KY	Yes	No	5-15	MD	Yes	Antistrip	5-15
NJ	Yes	No	5-15	ME	No	No	---
OH	Yes	No	9-17	MN	No	No	---
PA	No	Antistrip	5-15	RI	No	Silicone, Antistrip	5-15
VT	No	Antistrip	5-15	WV	No	No	---

Zone: Wet-No Freeze

Good Experience				Bad Experience			
State	Use Polymer	Use Other Additive	Percent Passing 2.36 mm Sieve	State	Use Polymer	Use Other Additive	Percent Passing 2.36 mm Sieve
AL	Yes	No	5-7	AK	No	No	--
FL	No	Crumb rubber	4-12	LA	No	No	>5-20
GA	Yes	Hydrated lime	5-10	TN	No	No	--
NC	Yes	Fiber	5-15				
OK	Yes	No	---				
SC	No	Hydrated lime	2-20				

Zone: Dry-Freeze

Good Experience				Bad Experience			
State	Use Polymer	Use Other Additive	Percent Passing 2.36 mm Sieve	State	Use Polymer	Use Other Additive	Percent Passing 2.36 mm Sieve
NV	Yes	Hydrated lime	---	CO	Yes	No	12-33
OR	Yes	Hydrated lime	---	ID	No	Antistrip	---
UT	Yes	Hydrated lime	14-20	KS	No	No	---
WY	Yes	Hydrated lime	10-25	SD	No	No	---

Zone: Dry-No Freeze

Good Experience				Bad Experience			
State	Use Polymer	Use Other Additive	Percent Passing 2.36 mm Sieve	State	Use Polymer	Use Other Additive	Percent Passing 2.36 mm Sieve
CA	Yes	No	7-18	HI	No	Silicone	5-15
NM	Yes	Hydrated lime	0-12				
TX	Yes	Fiber, crumb rubber	0-4				

Experience of states using polymer-modified binders has indicated that proper use of polymer and/or other additives can allow the use of high air voids (for drainage, and hence prevent stripping in the underlying layer) and high binder content (for durability, and hence prevent raveling of aggregates) by controlling draindown and can provide improved adhesion and greater resistance to aging of binder. It seems that a comparative study involving a number of additives is needed to evaluate the effectiveness of OGFC in terms of resistance to raveling, stripping, and draindown potential. A standard mix design procedure for OGFCs is also needed based on the experience gained with the FHWA design procedure and stone matrix asphalt mixtures, which use polymer-modified asphalt binders and/or fibers.

CONCLUSIONS

Significant improvements have been observed in the performance of OGFCs since their introduction in the 1950s. Although the experience of states with OGFC has been widely varied, half of the states surveyed in this study indicated good experience with OGFC. More than 70 percent of the states that use OGFC reported service life of 8 or more years. About 80 percent of the states using OGFC have standard specifications for design and construction. The vast majority of states reporting good experience use polymer-modified asphalt binders. Also, gradations of aggregates used by these states tend to be somewhat coarser than gradations used earlier and gradations used by the states that had bad experience with OGFC. It seems that good design and construction practice is the key to improved performance of OGFC mixes. An improved mix design procedure is needed to help the states adopt these good practices.

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