A Review of thePerformance Characteristics of Open Graded Friction Course Layer

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ABSTRACT
Open Graded Friction Course is a pavement layer laid as a surface course over the base course in pavements. Uniform aggregate gradation, lesser quantity of fines and filler materials give it a porous structure with increased percentage of air voids. The bitumen content for OGFC layer is slightly higher than that for conventional dense graded layer. OGFC has been used in various developed countries with high volume of traffic and rainfall intensity because of enhanced infiltration properties exhibited by the layer. The present study aims at providing a detailed review of the various problems encountered during the service life of Open Graded Friction Course as well as the measures that have been taken in order to tackle these problems in the past. Various benefits provided by Open Graded Friction Course to the pavement layer have also been discussed meticulously. Utilization of different types of polymers that have been obtained from waste recycling plants in modification of bitumen can provide a viable solution to improve the performance characteristics of Open Graded layer in addition to decreasing the burden of waste disposal on landfills throughout the country and achieving the goal of sustainability.

Keywords: Percentage air voids, Drain down, Abrasion, Ravelling, Polymer modifiers

I INTRODUCTION

Open Graded Friction Course is a distinctive pavement mixture that is being used as a thin surface course over the underlying impermeable layer in many countries all around the globe. OGFC mixture differentiates from the conventional dense graded mixes as it utilizes a coarser, uniform aggregate gradation and very less quantity of fine materials and fillers. As a result of gap graded aggregates, an open structure with large amount of interconnected air voids is produced which facilitates quick and efficient drainage of water from the road surface? Open Graded Friction Course employs a higher binder content than traditional dense graded mixes to augment durability of the structure.OGFC layers are usually provided as 20mm thick surface layers; however, in some of the European Countries, the thickness of OGFC layer varied from 20mm to 50mm. Friction Courses are also termed as popcorn mix or porous asphalt mix due to its gap graded structure. OGFC layer is typically provided on high speed and high volume roads, especially expressways so as to achieve the desired attributes of enhanced frictional resistance on the surface, improved vision at night and minimized hydroplaning.The design of OGFC layer is such that the quantum of air voids on the surface after spreading and compaction is in the range of 18%- 25%. These air voids facilitate eradication of water from the road surface. Approximately 50%-60% of the coarse aggregates used are of the same size and the filler content is restricted to 2%-5%. Due to uniform grading of aggregates and less quantity of filler, drainage of asphalt binder occurs from the mixture under gravity while storage and freightage to the construction site and this circumstance is commonly referred as draindown of bitumen. Another common problem being encountered in case of OGFC a pavement is ravelling which occurs when aggregates separate from the aggregate matrix as a consequence of wear and tear due to moving traffic loads. Presence of air and moisture in the layer due to open structure of OGFC layer increase the rate of acceleration of oxidation process of mix. The exposure of surface course to air and moisture results in premature aging of asphalt binder. As a result bitumen strips off the aggregates and the loose aggregates ravel to the surface. The phenomenon of ravelling goes on increasing exponentially, affecting the entire depth of OGFC segment over wide pavements. The following study provides a comprehensive view of the studies that have been carried out in the past to address these issues and the measures that have been taken to tackle these issues.

II PERFORMANCE OF OPEN GRADED FRICTION COURSE PAVEMENTS

The diverse advantages offered by OGFC pavements prompted highway engineers to use these mixes in many countries. These pavements provide added benefits during periods of longer storms by dissipating the pressure produced on road surface through voids present in the layer and thus maintaining a strong interaction between pavement and tire. Experimental studies have proven that an OGFC layer reduced water splash by up to 95% in comparison to that in dense graded layers. Furthermore, lesser thickness of Open Graded Friction Course layers lead to considerable amount of saving in the quantity of aggregates used in pavement construction.

However, use of coarser aggregate gradation results in high air content which aggravates durability issues, leads to pore clogging problems and demands special maintenance in colder regions. Depending on the weather conditions of area where OGFC layer is provided, the service life of pavements during which the frictional properties and texture are maintained varied from less than 6 years to more than 15 years.In contrast to the service life, the performance life of OGFC pavements during which characteristics like permeability and noise reduction remained intact ranges from 1-5 years. The performance life of these pavements can be increased by proper and periodic maintenance. The performance characteristics of OGFC pavements can be divided into two categories: Functional performance and Structural performance.

(a) **Functional Performance**-The functional properties of OGFC layer are dependent on the performance of void structure. The stone-on-stone matrix facilitates noise reduction and water infiltration, but also makes the pavement vulnerable to small particles which may clog the pores on the surface. Thus, periodic maintenance of OGFC pavements is necessaryso that the functional performance of pavement layer does not get affected. In addition to this, limiting the use of OGFC pavements to high speed roads is beneficial as it creates suction between the pavement and surface of tires and curbs clogging ability of smaller particles. Hence the permeability characteristics and noise reduction properties of the pavement layer can be prevented from getting exhausted by appropriate maintenance measures.

(b) **Structural Performance**-Typically OGFCs do not contribute to enhancing the structural capacity of the pavement. However, the durability of this layer affects the structural performance of the entire road structure. The main difference in the durability of traditional Hot Mix Asphalt and that of OGFC mix arises due to the open void structure of the latter as a result of which the water flows through the entire section rather than just on the top surface. Hence, the binder coating the aggregates gets oxidized by the oxygen flowing through the void structure and becomes brittle and strips off from the aggregates due to repeated wheel loads. In addition to this, another type of distress encountered in the OGFC layer is ravelling which occurs when aggregates still coated with bitumen get disintegrated from the pavement. Ravelling primarily occurs due to insufficient binder content and chemicals which may get ejected from vehicles. Ravelling can be identified as belonging to two different categories: Short term ravelling and long term ravelling (Molenaar and Molenaar, 2000). Short term ravelling occurs at the interface of tire and the pavement on newly placed OGFCs as soon as traffic is allowed on the pavements. This is mainly caused due to inappropriate mix temperature at the time of placement, draindown of binder during transportation and inefficient compaction. Long term ravelling occurs due to binder being drained down gradually over time. Thus the top of the wearing surface has lesser binder content than the rest of the layer and aggregates closer to the top surface get disloged under traffic movements (Molenaar and Molenaar, 2000).

III LITERATURE REVIEW

The studies carried out by various researchers on OGFC are as below:

Hanson and Shuler (1990) tested Open Graded Friction Course mixes in the laboratory to determine the stripping potential of the mix. Mixtures containing three different kinds of asphalts were prepared and subjected to a boiling test. These mixes were prepared with and without anti-stripping agents and hydrated lime. Further, the binders were modified with polymers and evaluated by boiling test. These mixes were prepared at Optimum Binder Content evaluated as per mix design procedure described by FHWA. Liquid antistripping agent was evaluated at two levels of concentration in each of the asphalts and modified by 3% copolymer by weight of binder. The analysis of test results was done by multiple or one-way Analysis of Variance (ANOVA). These test results indicated that mixtures containing liquid anti-stripping agents required lower binder contents. Polymer modified asphalt performed best when the mixture aggregate was treated with lime and least stripping of aggregates was observed. In comparison to other treatments, lime treated conventional OGFC mixture performed poorest and hence gave degraded field performance. However, addition of hydrated lime leads to an increase in the amount of binder content in OGFC mixture. Hence, further research has to be carried out to determine the sensitivity of mixtures to stripping depending on different binder contents.

Cooley et al. (2000) carried out study to evaluate the use of cellulose fibers in OGFC mixtures by entailing both field phase and laboratory phase. They selected six different OGFC pavements (with different binder polymer combinations) in Georgia constructed during 1992 and conducted visual distress survey during field investigation phase. Rut depth measurements were taken at each section along straight line and six cores were also excavated to obtain in-situ density and permeability. In the laboratory phase, number of moisture sensitivity tests was conducted on specimens prepared with both cellulose and mineral fibers. The mix design of these specimens was carried out according to Georgia Department of Transportation procedure for design of OGFC mixes. They used four different types of fibers: three types of cellulose fibers and a slag wool mineral fiber. They conducted four different types of tests: quantification of amount of water absorbed, Moisture Susceptibility by Diametral Tensile Splitting, Boil test and determination of rutting susceptibility by Loaded Wheel Tester after submergence at 60^0C. Based on the results of visual distress survey, the authors concluded that OGFC section containing cellulose fiber and no asphalt binder modifier performed better than other OGFC mixes in terms of reflective cracking and ravelling. However, the results of laboratory tests indicated that both cellulose fiber and mineral fiber mixtures performed well in extreme loading and weather conditions. Thus, to overcome the demerit of water absorption by cellulose fibers in case of heavy rainfall, mineral fibers can be used to produce pavements with increased infiltration.

Hassan et al. (2005) carried out research on different types of OGFC mixesto check suitability for their useon steep sloped hilly areas in Oman. It was desired to conceive a mix that would help in enhancing frictional properties of pavements in mountainous regions. Four different types of mixtures were prepared: without any additives, mix with 0.4% cellulose fibers by weight of total mix, 4% Styrene Butadiene Rubber by weight of binder and an optimum ratio of both the cellulose fibers and Styrene Butadiene Rubber. Various mixes were designed according to NCAT procedure at varying bitumen contents ranging from 4.5% to 6.5% and variations in percentage air voids, draindown of bitumen, unaged abrasion and aged abrasion were studied so as to come up with a mix which satisfies all the criterion as specified in NCAT procedure. It was deduced that the mixturewith both SBR and cellulose fibers at 6.5% optimum binder content meets up with all the standards. They further conducted Indirect Tensile Strength test so as to assess permeability and susceptibility to moisture at optimum binder content. This research led to the conclusion that an amalgamation of cellulose fibers and SBR polymer produced pavements with high ravelling resistance. However, better resistance to draindown was provided by use of cellulose fibers alone.

Alvarez et al. (2008) compared three different types of tests to identify the test which would be most convenient for design and performance evaluation of Open Graded Friction Course mix. The three different types of tests conducted were Cantabro Abrasion test (both in dry and wet conditions), the Wheel tracking test and the Overlay test. The authors conducted the study in two stages: the first stage involved testing on specimens with three different tests to check suitability for durability evaluation of mixes and the second stage focussed on appraising the preferred test to comprehend the results in terms of material quality, binder content and difference in mixture attributes after subjecting the compacted specimens to extreme conditions. They used two different types of asphalts: Type 1 Asphalt rubber (comprising minimum 15% by weight of asphalt of grade C crumb rubber) and Performance Grade Asphalt with minimum 1% dry aggregate lime and 0.2% cellulose fibers. The criterion used for identifying the appropriate durability test were specimen preparation, Air void content, equipment availability, testing time and variation in test results. Durability of PFC mixes is recommended to be tested by Cantabro test during mix design stage and production. Optimum Asphalt Content is to be determined by Cantabro test in a controlled temperature condition (25^{0}C). It is also observed that the resistance of mixture to fragmentation is influenced primarily by the properties of aggregates. However, they concluded that an improvised method of mix design has to be developed to assess the endurance of PFC mixes as Cantabro test gives variable results at different temperature conditions.

Shankar et al. (2008) carried out a study to differentiate the attributes of Porous Friction Course mixes prepared with conventional and modified binders for three types of aggregate gradations and two specified binder contents. The criteria for evaluation of performance were stone-on-stone contact, air voids and hydraulic-conductivity of specimens. Aged abrasion loss and moisture sensitivity were used to investigate the structural durability. The binder types used were neat bitumen, bitumen modified with polymers (plastomer and elastomer) and crumb rubber modified bitumen. Based on the analysis of results, it was found that the main cause of variation of response characteristics of PFC mixes is aggregate gradation and binder type. The mix with coarser gradation was found to exhibit lower bulk density, higher percentage air voids and better infiltration characteristics in comparison to other gradations. The results of Aged Abrasion Loss test indicated better resistance to abrasion for mixes prepared with CRMB modified binders. Dry and wet conditioned specimens prepared with polymer modified binders reported better Indirect Tensile Strength values in comparison to conventional and CRMB binders. Wet Abrasion Loss test values of CRMB mixes were lower as compared the mixes prepared with other binders and hence indicated more resistance to moisture induced damage. Thus, based on above observations it has been concluded that Porous Friction Course mixes prepared with modified binders and coarser gradations result in long lasting and stronger pavements even at lower compaction efforts.

Kowalski et al. (2009) monitored three highway test sections to evaluate friction, texture and noise properties over a period of 4 years. These highways were constructed using dense graded asphalt, stone matrix asphalt and porous friction course mixes. These pavements were tested periodically, about three times per year. The air temperature at the time of testing was between 5^{0}C and 34^{0}C and the pavement temperature was between 5^{0}C and 50^{0}C. These tests were conducted on both cloudy and sunny days with relative humidity ranging between 40% and 80%. The friction properties and texture of the pavement section were evaluated using dynamic friction tester, the locked-wheel friction trailer and circular track meter. Sound Pressure Level produced by interaction of tire and pavement was measured using Statistical Pass-By method and controlled Pass-by method. It was observed that friction of the pavement surface increased on initial exposure to traffic due to binder wearing off from the surface of aggregate particles and then starts to decrease to reach a stable value. Variations in temperature and degree of surface contamination due to changing seasons also control the frictional characteristics of the pavement. Measurements of tire-pavement noise on field indicated that Porous Friction Course is the quietest pavement surface out of the three surfaces. The noise levels of PFC mix was found to increase as the cumulative traffic level increases. After four years of periodic observations, the authors have suggested that PFC layer can prove to be a viable pavement surface with good friction and reduced tire-pavement noise.

Belshe et al. (2011) studied the suitability of providing OGFC layer on concrete pavements and the effect it produces on the temperature gradient and curling stresses across the pavement thickness. They selected a study site at Interstate Ray Road in Phoenix. The pavement north of Ray Road had been laid with OGFC layer and South of Ray Road was laid simply with PCC. Sensors to detect temperature variations were placed at varying depths both in the lane and shoulders of the road at six different locations. This data was collected in the month of June and December to account for extreme temperature conditions and the data obtained was subjected to three-dimensional finite-element analysis to study daily as well as seasonal temperature variations. It was concluded that providing an OGFC layer reduces temperature differentials between the top and bottom of the slab due to increased aeration effect as a result of open graded structure. Results of Finite Element Analysis also display reduction in curling stresses when friction course is provided over PCC pavement. A non-linear temperature profile was observed across the slab thickness in both summer and winter season. Thus reduction in temperature variation by providing OGFC layer can help curb the curling stresses which are damaging to the concrete pavements.

Bose et al. (2012) studied the influence of polymer additives like crumb rubber and reclaimed polyethylene on the properties of OGFC mixtures. They carried out a comparative study of polymer modified mixes and mixes prepared using conventional binders based on different properties like draindown, abrasion, permeability, resistance to rutting, moisture sensitivity and skidding. Two variations of Marshall Compaction were used to prepare mixes at four different binder contents; in the first type, mixtures were given 25 blows on each face and in the second type, only one face was compacted by giving 50 blows. The binder used was modified by different percentages of crumb rubber and reclaimed polyethylene. It was observed that when polymer modified binders were used to prepare specimens, they exhibited an increase in the Indirect Tensile Strength values and were less susceptible to variation in moisture content. Mixes prepared by compaction with 50 blows surfaced better when subjected to abrasive conditions. Use of Polymer modified binders increased the fatigue life of OGFC mixes by approximately 50% in comparison to traditional HMA mixes.

Chen et al. (2012) studied the top-down cracking performance of Open Graded Friction Course pavements and the effect of characteristics of interface conditions on this performance. Top-down cracking is one of the chief modes of distress of OGFC layer because of its low fracture resistance in comparison to conventional dense graded mix. The cracking performance of thin OGFC layer relies on the characteristics of the following three components close to pavement: OGFC, structural layer lying underneath and the interface condition between them. Hence to ensure an interface resistant to fracture, different types of tack coats were applied and tested using a newly developed composite specimen interface cracking test. They also employed X-ray computed tomography to analyse the interface characteristics. They prepared three sets of composite specimens all dense graded, OGFC on dense graded mix coated with Polymer Modified Asphalt Emulsion and OGFC on dense graded mix coated with conventional tack coat. Hot Mix Asphalt mechanics was used to quantify the structural effect of different types of tack coats on top down cracking performance. The analysis of results clearly indicated that use of Polymer Modified Asphalt Emulsion as tack coat increases the fracture resistance of OGFC layer. This result was further verified by obtaining crack tip stress distribution from Two-dimensional plane stress FEM model of specimens.

Putman and Wurst (2013) studied the expediency of using Warm Mix Asphalt technology for producing OGFC mixes so as to eliminate the need of stabilizing fibers in the mixture. The two WMA technologies used were Evotherm and Foaming techniques. Three primary criterions, viz: Draindown, air voids and abrasion were used to draw a comparison between mix prepared using HMA technology and WMA technologies. Additionally, two additives i.e. hydrated lime and cellulose fibers were introduced to serve as anti-stripping agent and avoid excess binder draindown in HMA mixes, respectively. The results of these comparisons indicate that use of WMA technology eliminated the need of using fibers thus enhancing the permeability characteristics of pavements to almost twice as compared to HMA mixes. In addition to this, WMA mixes exhibited better durability than HMA mixes in both dry and wet conditions. Use of WMA technology also contributed towards reducing consumption of energy sources and emissions from paving mixes.

IV CONCLUSION

The major issues encountered in Open Graded Friction Course pavements are use of excessive binder due to draindown and loss of material due to ravelling. The Hot Mix Asphalt technology used for laying OGFC pavements has lead to an increased energy consumptionand emission of toxic gases into the surroundings. Various researchers all around the world have carried out work in order to identify measures to tackle these problems in different topographical and climatic conditions. Incorporation of polymer modifiers has contributed to a great extent in addressing the issue of lesser durability as they make binder stiff and prevent ravelling from pavement surface. Use of cellulose and mineral fibers have considerably solved the problem of binder draindown during transportation and placing of the mixture. In addition to polymer modifiers and fibers, using hydrated lime in small percentages can help in solving the issue of binder stripping off the aggregate particles. However, these measures have led to an increase in the cost of pavements by approximately 30% as compared to traditional dense graded pavements. Hence it is desirable to identify certain materials that could be helpful in overcoming the major issues encountered in OGFC pavements while taking into consideration the economics of construction of long lasting pavements and sustainability of the environment.

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