Laboratory evaluation of durability of open-graded friction course Mixtures

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Abstract—Open-graded friction courses (OGFC) are special purpose thin surface mixtures of hot mix asphalt (HMA) pavement that is increasingly being used around the world. Owing to its safety aspects, OGFC is being regularly used as final riding surface on interstate and high speed expressways by different highway agencies in United States, including Alabama Department of Transportation. OGFC pavements in Alabama are facing premature failure due to different reasons. Loss of durability and functionality causes failure of OGFC pavements. Thus, research is needed to improve the durability of OGFC and enhance its beneficial properties. This research proposes methods to improve the durability of OGFC mixtures through laboratory performance testing. Aggregate gradation and layer thickness significantly affected the durability of the OGFC surfaces in general, especially the layer thickness. The Hamburg test indicated a 50-60% higher resistance to moisture damage of OGFC pavement with increase in thickness from 19 mm to 38 mm. The Cantabro stone loss of OGFC pavements is reduced 10-50% with increase in thickness from 19 mm to 38 mm. The permeability tests results indicated 12-100% increase in permeability with increase in thickness of OGFC pavement from 19 mm to 38 mm. Indirect tensile strength tests indicated 50-300% increase in strength with increase in thickness of OGFC pavement from 19 mm to 38 mm.

Keyword- open-graded friction course, durability, gradation, layer thickness

I. INTRODUCTION

Open-graded friction courses (OGFC) are special purpose thin surface mixtures used to reduce the risk of hydroplaning, wet skidding, splash and spray, pavement noise and improve night and wet weather visibility of pavement markings [1]. OGFC are frequently used as surface layers in countries like United States of America, Japan, United Kingdom, Malaysia, Australia, New Zealand and South Africa for more than 60 years on high speed highways and interstate expressways [2, 3]. The cross-section details of a typical flexible pavement with OGFC on top are illustrated in Figure 1.

Although Federal Highway Administration (FHWA) developed a mix design procedure for OGFC in 1974, revised in 1990, the procedure was adopted by different state departments of transportation (DOTs) with wide variety [4]. This variation in mix design process led to inconsistency in long term performance. When the Superpave mix design method was introduced and state agencies started adopting this technology for design of dense graded mixtures, there was a need to incorporate the Superpave technology into the OGFC mix design method. A provisional mix design procedure was developed by National Center for Asphalt Technology (NCAT) for new generation of OGFC mixes based on comprehensive research, and European and state agencies' experiences [5, 6]. The method incorporated the Superpave specifications into the OGFC mix design method and generally recommends coarser gradations and thicker OGFC layers as compared to previous FHWA method. The layer thickness for OGFC pavement depends upon number of factors including gradation (fine, medium or coarse) selected and nominal maximum aggregate size (NMAS). ASTM has incorporated OGFC design procedure in ASTM standard D7064/ D7064M "Standard Practice for Open-Graded Friction Course (OGFC) Mix Design".

Loss of durability and functionality causes failure of OGFC pavements. A successful mixture design method for OGFC should be capable of producing a functional and durable pavement during its service life. The design practice followed by all agencies measured mixture functionality, but did not directly accounted for the durability. Empirical methods have been used to evaluate durability in OGFC mixtures which include retained tensile strength ratio (TSR), the Hamburg wheel tracking device (HWTD) test, indirect tensile (IDT) strength, Cantabro test, draindown test and permeability test.

The HWTD was introduced in the United States as a result of the 1990 European Asphalt Study Tour. The HWTD was manufactured and first time used in Hamburg, Germany, and it was being used as a performance test to evaluate both rutting and moisture susceptibility of asphalt mixtures in Europe [7]. The HWTD test procedure has been described in AASHTO T 324-04 (2008): “Hamburg Wheel-Track Testing of Compacted Hot Mix Asphalt (HMA)” and requires a steel wheel with a load of 158 lbs. traveling in a reciprocal motion over immersed samples. The test will provide a graph of deformation over 20,000 wheel passes. If a mixture is susceptible to moisture damage, it will have both a rutting slope and a stripping slope as indicated in Figure 2. Figure 2 clearly shows that, the farther the stripping inflection point in terms of wheel passes means more moisture susceptibility with lesser slope and rut depth. Generally, less rut depth within OGFC mixtures will mean less moisture susceptibility. The HWTD has been found to have excellent correlation with field performance (especially in moisture damage evaluation) [8-10].

The Cantabro test is a European procedure that indicates mixture resistance to wear and ravelling [7, 11] and has been recommended as a potential test for use in standard OGFC mix design procedure based on previous NCAT research [6, 12] and ASTM D7064/ D7064M-08 (2013) “Standard Practice for Open-Graded Friction Course (OGFC) mix Design”. This test is described in prEN 12697-17 “Determination of the Abrasion of Porous Asphalt”. This test has been used to predict the durability of OGFC pavements in laboratory and during service life.

The IDT strength test has been widely used for HMA mixture design and is used by some of European countries i.e., Netherland and Spain for porous pavement design. The results of IDT strength test were used to obtain the comparative strength of OGFC mixtures and predict the rutting and raveling potential. Since the performance of porous mixtures depends on tensile strength of binder, the IDT strength is also important test for OGFC mixtures [13].

Permeability is the most influencing factor affecting the durability and long term performance/ functionality of OGFC pavement, and air voids are an indicator of permeability characteristics. The in-place permeability of pavements is directly related to the amount of interconnected voids. It’s not just air voids content, but size, orientation and interconnectivity that affect the permeability characteristics of HMA [14]. Amount of interconnected voids present in a mix is significantly affected by gradation and NMAS. Permeability potential of mixes increase with an increase in air voids, coarseness and NMAS [15]. A minimum lab permeability of 100 m/day is recommended for OGFC mixtures by NCAT and ASTM as optional test to ensure its functionality [12]. TxDOT recommended a maximum Water flow value (WFV) of 20 seconds in initial stage of PFC pavement to ensure required permeability in the field because of differences in field and lab permeability values. In Belgium and UK field permeability of PEM pavements is done before trafficking to ensure its functionality. In Denmark, both lab and field permeability, whereas in Spain lab permeability tests are done on PEM pavements before they are ready for the traffic [3, 16]

Owing to its numerous benefits, OGFC is being regularly used as final riding surface on interstate and high traffic expressways by different highway agencies in United States, including Alabama Department of Transportation. OGFC pavements in Alabama are facing premature failure due to different reasons. Thus, research is needed to improve the durability of OGFC and enhance its beneficial properties. This research proposes methods to improve the durability of OGFC mixtures through laboratory performance testing.

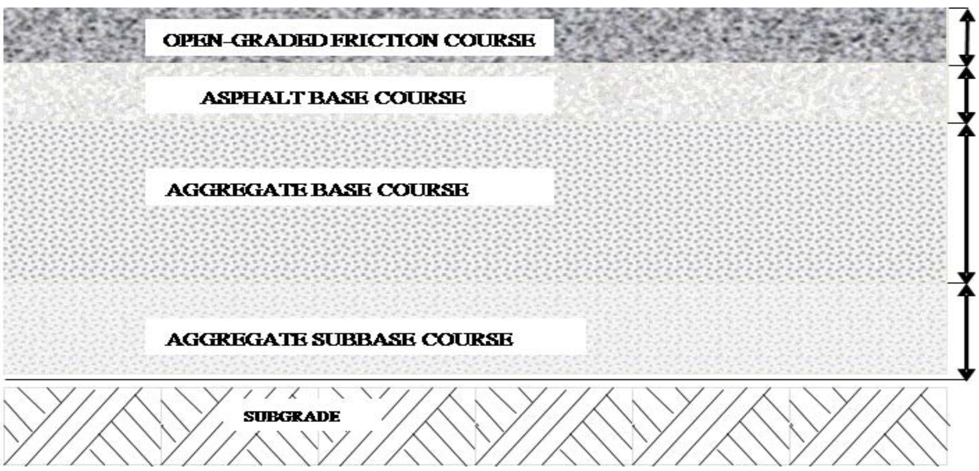

Fig. 1. Cross section details of a typical OGFC pavement

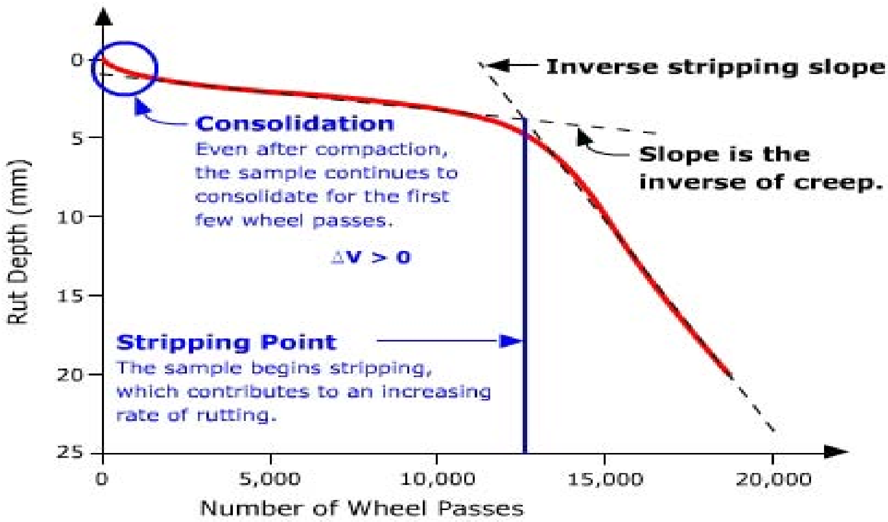

Fig. 2. Hamburg wheel-tracking device test results [17]

II. RESEARCH PLAN

A. Research Significance

Majority of states in USA are following the design method suggested by National Center for Asphalt Technology (NCAT) in 2000 and refined in 2005. ASTM has incorporated OGFC design procedure in ASTM standard D7064/ D7064M-08(2013) "Standard Practice for Open-Graded Friction Course (OGFC) Mix Design". A typical layer thickness for new generation OGFC mixes is about 32 mm, but different agencies are using layer thicknesses in ranges from 19-32 mm. After 2005, only Texas Department of Transportation (TxDOT) conducted significant research related to OGFC which concluded in 2007. TxDOT research was aimed at enhancing functional performance instead of improving durability of OGFC mixtures. The significance of this research is to study the effect of design parameters i.e., aggregate gradation and layer thickness through laboratory performance testing to improve durability of OGFC mixtures.

B. Methodology

The research methodology for evaluating the effect of design parameters i.e., aggregate gradation and layer thickness to improve durability of OGFC mixtures based on durability and strength properties is as illustrated in Figure 3.

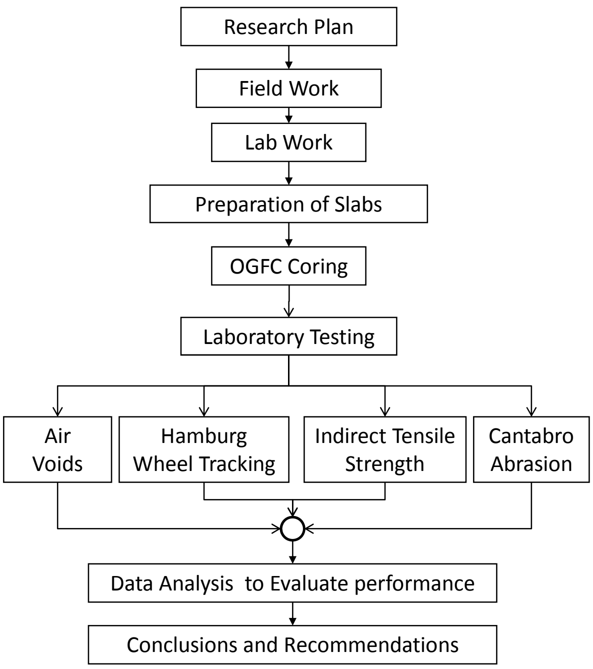

Fig. 3. Research Methodology for improving durability of OGFC mixtures

C. Selection of Projects

The first task in this research study was to identify the ongoing OGFC projects in Alabama so that they can be replicated in the laboratory. Ongoing projects were selected to include latest trends incorporated by ALDOT in OGFC mix design. With Alabama Department of Transportation (ALDOT's) current mix gradation and placement thickness, a thickness/ nominal maximum aggregate size (NMAS) ratio of 1.4 is obtained. A review of OGFC performance at National Center for Asphalt Technology (NCAT) test track showed better performance by ALDOT OGFC mixtures having thickness/ NMAS ratio of about 2.5. To increase thickness/NMAS ratio, either additional thickness is provided or gradation be made finer. To decide about, either of above mentioned options, to improve thickness/NMAS ratio for better performance, projects were selected. Projects were selected as coarser gradation project (US 80) and finer gradation project (E-9A). The design of all above mentioned projects were based on current ALDOT recommended method.

III. LABORATORY INVESTIGATIONS

Loose mix, virgin aggregate and binder were collected from the plant feeding to OGFC project (US 80) located in Sumter County and plant feeding to OGFC project (E9A) at NCAT test track. The material was brought back to NCAT for testing. For the US 80 project, an OGFC mix design was performed using the ASTM method with gyratory compacter. The loose aggregate, fiber, and binder used were collected from the plant site of the project in Sumter County. The binder content used for mix design process was (+0.5 and -0.5%) of JMF (6.3%) used at the plant site. This step was done to confirm that design is according to specifications.

From the loose mix, 2 different slabs were prepared for each of the two projects at 19, 25, 32 and 38 mm, respectively. The slabs were prepared according to NCAT specified procedure. From each slab, 10 cores were taken: Four 150 mm diameter and six 100 mm diameter specimens. The four 150 mm diameter cores were used to make two replicates for Hamburg testing. Three of the 100 mm cores were tested for Cantabro, and the other three 100 mm cores were tested for permeability (using two different saturation techniques: vacuum and submerged saturation). The three permeability cores were then conditioned and tested for tensile strength after one freeze-thaw cycle. Permeability testing for this research was accomplished using a falling head test (ASTM PS 129-01). This provisional standard is no longer used by ASTM; however it is similar to Florida Method (FM5-565).

A summary of the OGFC projects (E9A and US-80) is given in Table 1. A summary of the experimental plan for the research is presented in Table 2.

TABLE 1 Summary of OGFC projects selected for performance testing

Test Section	**Location**	**Study Mix (mm)**	**Aggregate**	**AC (%)**	**Specified Binder**
E9A	Test Track	19 (Finer Gradation)	Granite	6	PG 76-22 with cellulose Fibers
US 80	Sumter County	19 (Coarser Gradation)	Sand Stone	6.3	PG 76-22 with SBS

TABLE 2 Experimental plan for research

Description	**Quantity**	**Notes**
Projects Evaluated	2	2 OGFC projects : 1 at NCAT test track; one in Sumter county
Slab Thickness Used	4	19, 25, 32, 38 mm
No. of Slabs	8	2 Projects × 4 Thicknesses
For each slab:		
G_{mb}	10	All cores
Permeability Test	3	3 replicates
Cantabro Test	3	3 replicates
Hamburg Test	4	2 cores used for one Hamburg test × 2 replicates
IDT	3	3 replicates (3 cores after permeability were conditions and tested for IDT strength after one freeze-thaw cycle.
G_{mm}	4	All 3 cores after IDT
No. of cores tested	80	8 slabs × [3 + 3 +4]

IV. DISCUSSION ON LABORATORY TESTS

A. Hamburg Tests

Analysis of Hamburg rut depth was conducted to evaluate the improvement in resistance to rutting and/or moisture susceptibility for different projects and thicknesses. Figure 4 and 5 shows the average rut depth (using the Hamburg rutting procedure) and air voids of cores for US 80 and E-9A. Analysis of variance (ANOVA) tests comparing the rut depth to thickness were conducted together for projects US 80 and E-9A. In these ANOVA tests, the responses were rut depth, and the effects included thicknesses. The results of these ANOVA tests at the 95% confidence level (P = 0.034 and R2 = 31.21%) showed that the rut depth was statistically significant ($P < 0.05$) to thickness. The R2 value of 31.21% for a comparison between thickness and Hamburg rut depth indicated weak relationship. HWTD test results clearly showed a trend of reduction in rut depth with increased thickness in case of projects US 80 and E9A. Based on these results, it appears that increase in OGFC thickness improve performance in resistance to rutting/moisture damage to some extent.

Hamburg test results show a significant reduction in rut depth when thickness is incresead from 25 mm to 32 mm for projects US 80 and E-9A. The increase in thickness strengthens the bond between aggregate and asphalt thereby reducing the moisture damage to the pavement. Air voids lie in the range of 13-14.5 % for thickness in range of 32-38 mm of OGFC cores. Although air voids seem to be less than the specified minimum air voids according to ASTM standard D7064/ D7064M-08(2013) "Standard Practice for Open-Graded Friction Course (OGFC) Mix Design" (18%) but seems closer to ALDOT method (15%). Figure 4 showed that the OGFC project with coarser aggregate gradation (US 80) has more moisture susceptibility as compared to finer aggregate project (E-9A). Based on these results a minimum of 32 mm thickness is recommended to reduce moisture susceptibility in OGFC pavements.

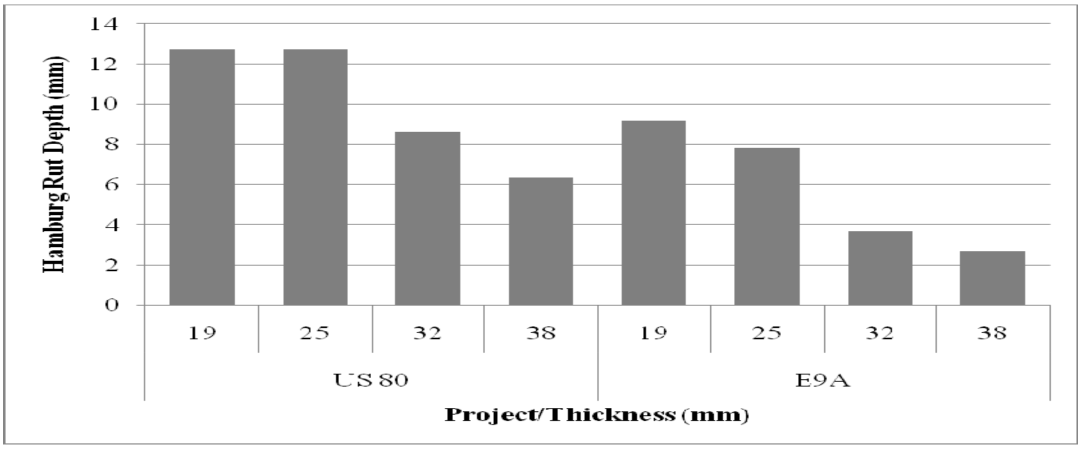

Fig. 4. Average Hamburg rut depth of OGFC projects

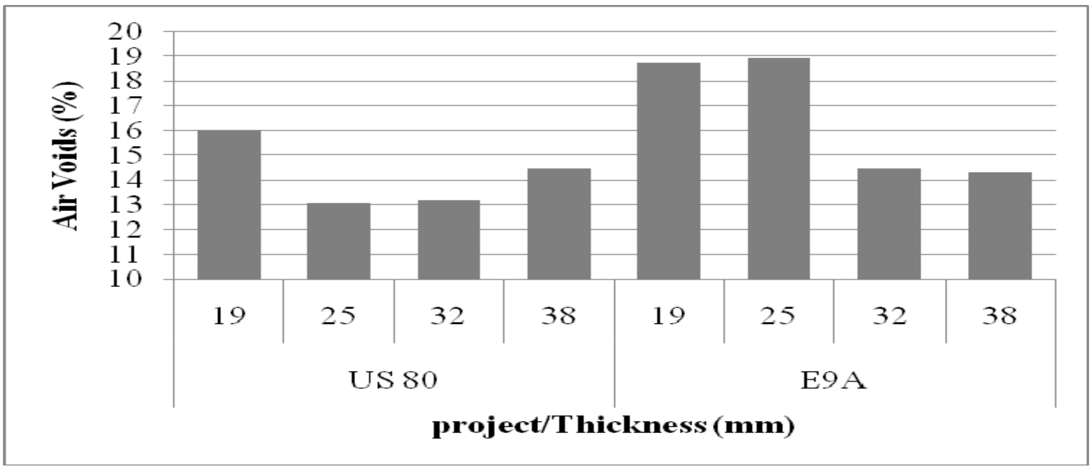

Fig. 5. Average air voids of OGFC projects for Hamburg tests

B. Cantabro Tests

Analysis of Cantabro percent loss was conducted to evaluate the improvement in resistance to wear and raveling for different projects and thicknesses. Figure 6 and 7 shows the Cantabro percent loss results and air voids of cores for projects US 80 and E-9A. ANOVA tests comparing the stone loss to thickness were conducted together for projects US 80 and E-9A. In these ANOVA tests, the responses were stone loss, and the effects included thicknesses. The results of these ANOVA tests at the 95% confidence level ($P < 0.001$ and R2 = 42.92%) showed that the stone loss was statistically significant ($P < 0.05$) to thickness. The R2 value of 42.92% for a comparison between thickness and Cantabro stone loss indicated that relationship is quite strong. ANOVA results indicated that the increase in thickness of OGFC pavement significantly affected Cantabro stone loss, showing improvement in resistance to wear and raveling.

Cantabro test results show a significant reduction in Cantabro stone loss when thickness is increased from 32 to 38 mm for projects US 80 and E-9A. Although, Cantabro stone loss in both projects was beyond the specified American standard of testing material (ASTM) criteria, but that can be attributed to compaction procedure adopted for preparation of slabs. The probable cause of reduction in raveling susceptibility with increase in thickness of OGFC is enhanced internal cohesion through aggregate particle interlock. Increase in thickness of OGFC layer increases the thickness/NMAS ratio with better aggregate skeleton. In case of project E-9A reduction in stone lost with increase in thickness is nominal whereas in US 80 projects there is marked improvement in raveling resistance on thicknesses of 32mm onwards, probably due to coarser gradation. Figure 6 showed that the OGFC project with coarser aggregate gradation (US 80) are more durable (less cantabro stone loss), especially for 38 mm layer thickness, as compared to finer aggregate project (E-9A). These results indicate that an improvement in resistance to wear and raveling is directly proportional to thickness if it is beneficial in enhancing internal cohesion through aggregate particle interlock.

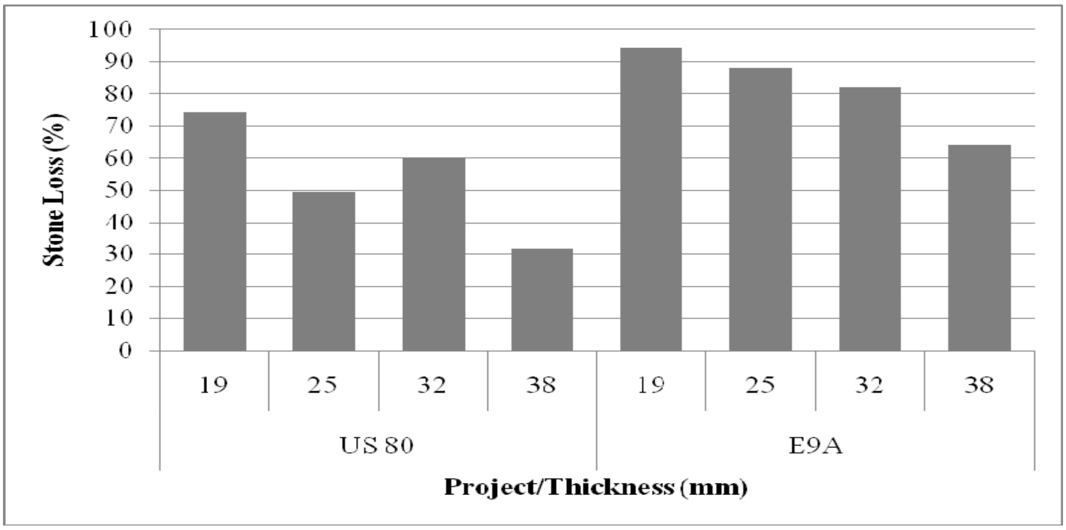

Fig. 6. Comparison of OGFC projects and thickness to Cantabro stone loss

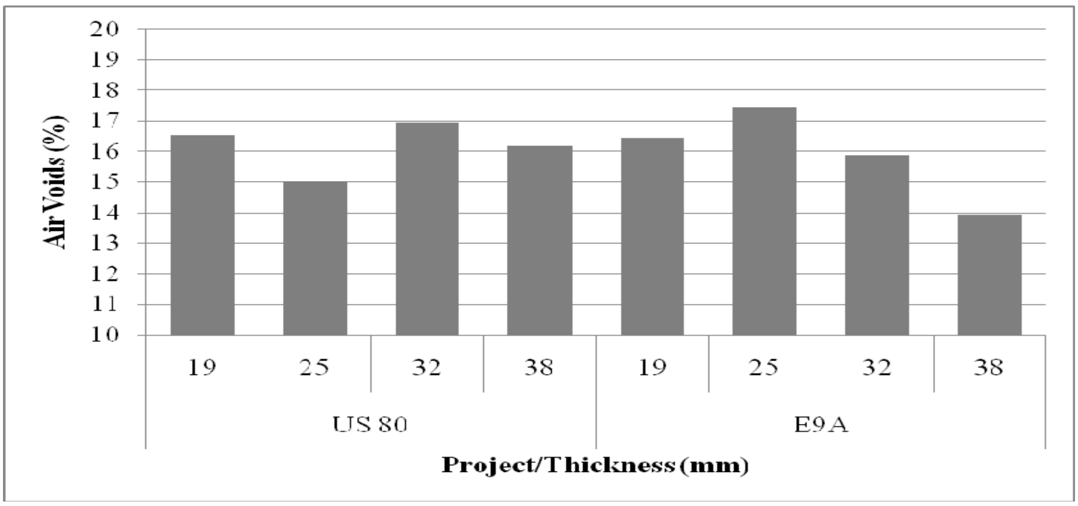

Fig. 7. Average air voids of OGFC projects for Cantabro tests

C. Permeability Results

Analysis of permeability for different projects was conducted to evaluate the variation in water transmission characteristics for different projects and thicknesses. Figure 8 shows the permeability test results of cores for US 80 and E-9A. ANOVA tests comparing the permeability to thickness were conducted together for projects US 80 and E-9A. In these ANOVA tests, the responses were permeability, and the effects included thicknesses. The results of these ANOVA tests at the 95% confidence level (P = 0.033 and R2 = 25.03%) showed that the permeability was statistically significant (P < 0.05) to thickness. The R^2 value of 25.03% for a comparison between permeability and thickness indicated that a relationship existed between variables of permeability and thickness.

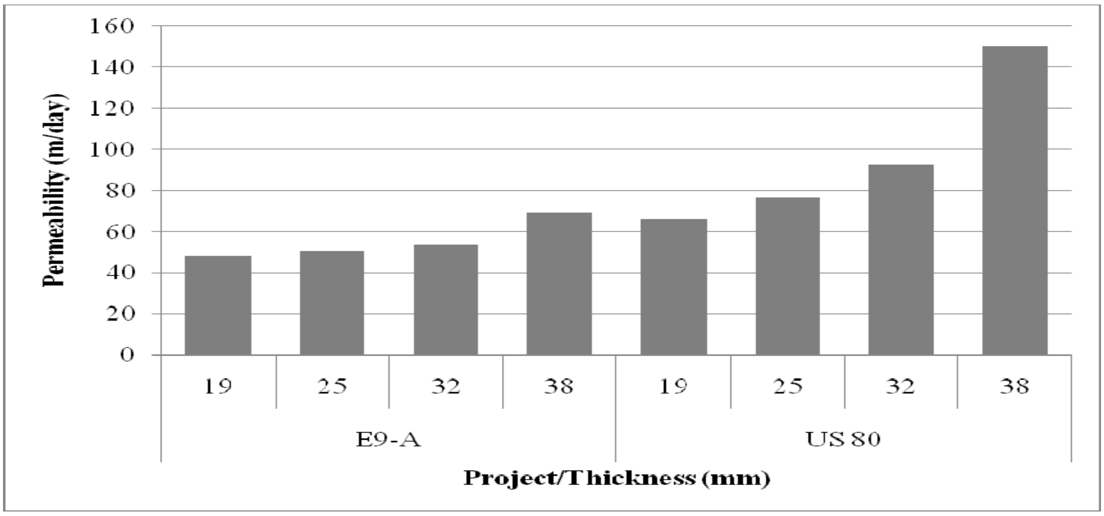

Fig. 8. Comparison of OGFC projects and thickness to permeability

Project US 80 gives better permeability than E-9A and only 38 mm thickness of US-80 project met the criteria of 100 m/day set by ASTM. Although air voids for both projects are generally in the same range (15-18%), US 80 better permeability is probably due to coarser gradation. Permeability value of more than 140 m/day for 38 mm OGFC core of project US 80 is probably due to coarser gradation, more air voids and thickness. These results indicate that an improvement in internal cohesion through aggregate particle interlock can be better achieved by increasing the thickness of OGFC pavement surface layer instead of making the gradation finer. Based on these results a minimum of 38 mm thickness is recommended to meet the criteria of 100 m/day set by ASTM.

D. Indirect Tensile (IDT) Strength

Analysis of indirect tensile (IDT) strength was conducted to evaluate the variation in strength for different projects and thicknesses. Figure 9 and 10 shows the IDT results and air voids for projects US 80 and E-9A. The IDT strength values of the cores of all project locations were ranging between 100 KPa and 750 KPa with average of 495 KPa. The probable cause of variability in IDT strength values within project cores is weak spots because thicknesses of the cores were very less. This is true as the IDT strength test is sensitive to the thicknesses of cores and thicknesses were less than the minimum thickness values specified by ASTM D 6931-07, which is 38 mm.

ANOVA tests comparing the IDT strength to thickness were conducted together for projects US 80 and E-9A, In these ANOVA tests, the responses were IDT, and the effects included thicknesses. The results of these ANOVA tests at the 95% confidence level (P = 0.071 and R^2 = 16.19%) showed that the IDT strength was statistically significant (P < 0.05) to thickness. The R^2 value of 11.21% for a comparison between IDT strength and thickness indicated that relationship was also not that strong. As can be seen in Figure 9, the general trend is to have more IDT value with thicker cores in case of projects US 80 and E-9A. Figure 9 showed that the OGFC project with coarser aggregate gradation (US 80) have less IDT strength, as compared to finer aggregate project (E-9A). These results indicate that thickness of more than 32 mm should be used to get optimum strength characteristics of OGFC pavement.

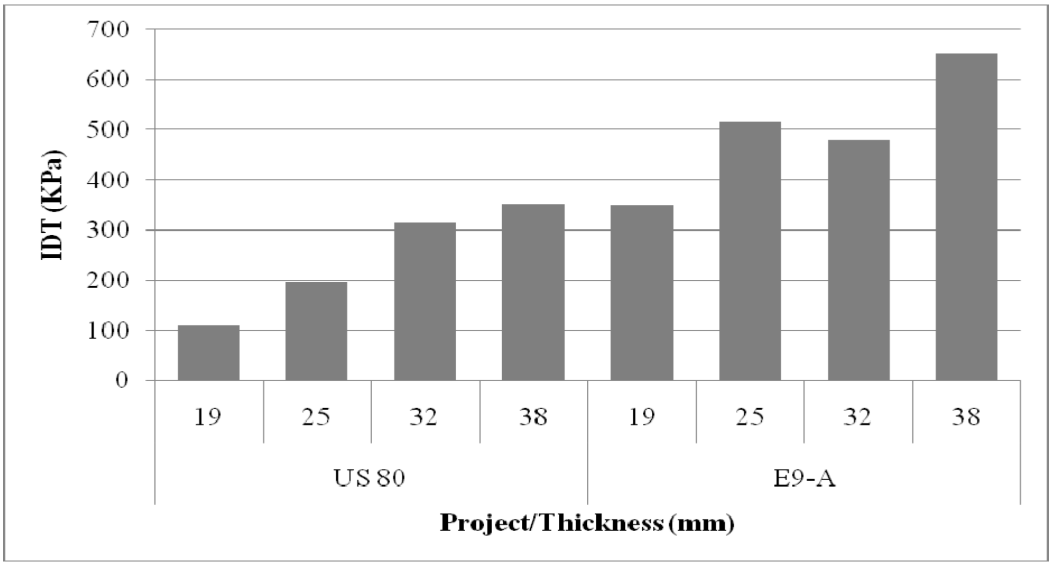

Fig. 9. Comparison of OGFC projects and thickness to IDT strength

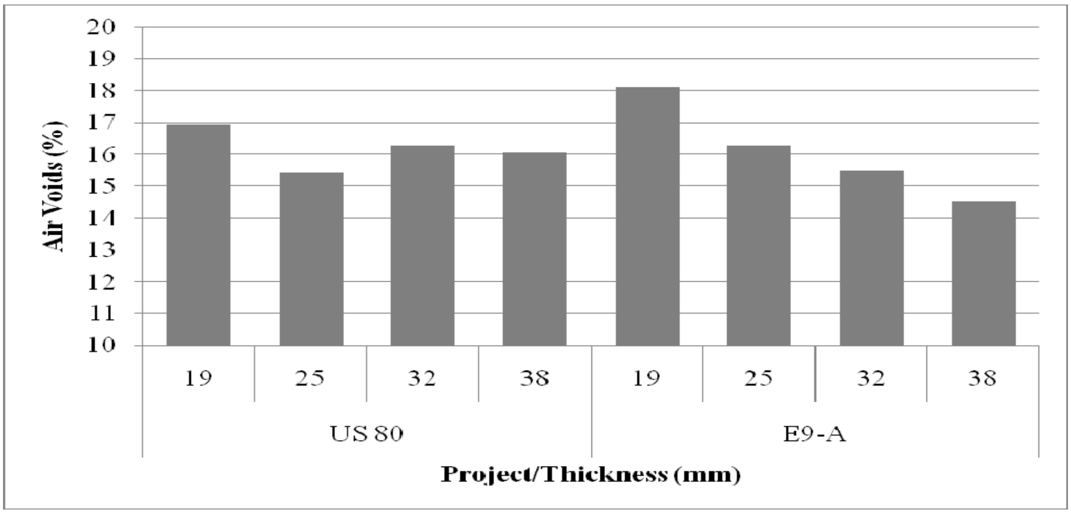

Fig. 10. Average Air Voids of OGFC projects for IDT strength tests

V. CONCLUSIONS

Based on laboratory investigations and data analysis conducted during laboratory performance tests to evaluate durability of OGFC mixtures, the following conclusions are inferred:

Aggregate gradation and layer thickness significantly affected the durability of the OGFC surfaces in general, especially the layer thickness. The HWTD test indicated a 50-60% higher resistance to moisture damage of OGFC pavement with increase in thickness from 19 mm to 38 mm. There was a significant decrease in moisture susceptibility when thickness of OGFC layer was increased from 25 mm to 32 mm based on results of HWTD test. Coarser aggregate gradation project (US 80) has shown more moisture susceptibility as compared to finer aggregate project (E-9A) based on HWTD test results. The Cantabro stone loss of OGFC pavements is reduced 10-50% with increase in thickness from 19 mm to 38 mm. Cantabro test results show a significant reduction in stone loss when thickness is increased from 32 to 38 mm for projects US 80 and E-9A. OGFC project with coarser aggregate gradation (US 80) are more durable (less cantabro stone loss), especially for 38 mm layer thickness, as compared to finer aggregate project (E-9A). The permeability tests results indicated 12-100% increase in permeability with increase in thickness of OGFC pavement from 19 mm to 38 mm. Permeability test results show a significant increase in permeability when thickness is increased from 32 to 38 mm for coarser aggregate gradation (US 80). OGFC project with coarser aggregate gradation (US 80) are more permeable as compared to finer aggregate project (E-9A). IDT strength tests indicated 50-300% increase in IDT strength with increase in thickness of OGFC pavement from 19 mm to 38 mm. OGFC project with coarser aggregate gradation (US 80) have less IDT strength, as compared to finer aggregate project (E-9A). Improvement in resistance to wear and raveling along with increase in permeability with increase in thickness of OGFC layer is observed, if, it increases the thickness/ nominal maximum aggregate size (NMAS) ratio, also.

VI. RECOMMENDATIONS/FUTURE RESEARCH IMPLICATIONS

In order to expand and further validate this research, it is recommended to conduct laboratory investigation on OGFC samples beyond 38 mm thickness to broaden the scope and efficacy of the research. It is further recommended to include others tests in laboratory investigations to predict durability of OGFC pavements.

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