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Full Paper

Effects of rejuvenator seal and fog seal on performance of open-graded friction course pavement

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Abstract: An open-graded friction course (OGFC) is a special-purpose surface layer of hot-mix asphalt (HMA) pavement that is increasingly being used around the world. Owing to its numerous benefits, OGFC is being regularly used as a final riding surface on interstate and high-traffic expressways by different highway agencies in the United States. However, some OGFC sections have experienced premature failure due to ravelling only after 6-8 years of service life. To maintain an effective, longer service life and enhanced performance of OGFC, preventive maintenance has been considered essential. There are several approaches to maintaining OGFC, one of which is the application of a fog seal and rejuvenator seal. A fog seal can reduce ravelling and extend the service life of OGFC while a rejuvenator seal can revitalise the existing aged asphalt binder in the top OGFC layer. This research focuses on optimising the fog and rejuvenator seal application rates by evaluating their effectiveness in terms of surface friction and durability. Three types of seal material were evaluated: Pavegaard (PG) and Pavepreserve (PP) asphalt rejuvenators and a cationic slow-setting asphalt emulsion (CSS-1H) as a fog seal. Improvement in abrasion resistance of OGFC pavement was observed on application of fog and rejuvenator seals but surface friction was reduced to some extent. Hamburg test clearly shows a trend that the medium application rate of 0.10 gallon/square yard is better in enhancing resistance to rutting/moisture susceptibility of OGFC.

Keywords: rejuvenator seal, fog seal, hot-mix asphalt pavement, open-graded friction course, surface friction

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INTRODUCTION

An open-graded friction course (OGFC) is a thin and permeable surface layer of a hot-mix asphalt (HMA) mixture that incorporates a coarse aggregate skeleton with minimum fines. The load is supported through stone-to-stone contact and the asphalt binder keeps the skeleton intact. This inherent attribute of OGFC enhances resistance to rutting and its porous nature ensures immediate drainage of water from the pavement surface. It provides numerous benefits for the road users in terms of safety, environment and economy, including improved friction, minimised hydroplaning, reduction of splash and spray, improvement of night visibility and reduction of noise level [1]. However, the damaging actions of air, water, temperature and traffic over time raise durability issues in OGFC pavements. These issues lead to the problem of ravelling and reduced performance life [2, 3].

Advances in mixture design, construction techniques and practices, and use of durable materials, especially fibre- and polymer-modified asphalt binders have improved the performance and durability of OGFC pavements [4]. Regular preventive maintenance is one of the key measures to maintain good performance and durability of the OGFC pavement during its service life. Surface cleaning and application of fog seals or rejuvenator seals are two major methods used in preventive maintenance of OGFC. The surface cleaning technique is mainly adopted in Europe and Japan to maintain porosity and unclog OGFC pavements. Current maintenance activities in Denmark include cleaning of the voids by high-pressure water and air suction twice a year in order to maintain porosity during the pavement lifetime [5]. On the other hand, Japan is adopting frequent cleaning operations with only partial debris removal during each cleaning operation [6]. High-pressure washing is currently quite expensive and of questionable value. It is believed by local agencies in the United States that the OGFC functionality can be maintained by its self-cleaning capacity created in highways with relatively high-speed and high-volume traffic because of the suction generated by rolling tyres on the pavements [7].

Fog seal application is used as one of the preventive maintenance techniques in 5 out of 17 states in the US, where OGFC is routinely used. It provides a small film of unaged binder at the surface but friction and reduction in porosity can still be expected [8, 9]. The Federal Highway Administration recommends fog seal in two applications at a rate of 0.05 gallon/square yard (gal/sy) for each application, using a 50% dilution of asphalt emulsion without any rejuvenator agent [10]. Fog seal is utilised in New Mexico, Wyoming, South Carolina, Oregon and California to execute preventive maintenance [9, 11]. It is typically a light spray application of dilute asphalt emulsion used primarily to seal the existing asphalt surface to reduce ravelling and enrich a dry and weathered surface [12]. It enriches the top aged surface and its penetration to a certain depth is expected to extend the service life of OGFC [7, 13, 14]. Rejuvenator seals are maltene-based petroleum products that revitalise the existing aged asphalt binder in the top OGFC layer [15, 16]. The effectiveness of a rejuvenator is judged by the deep penetration to avoid a slippery surface. The main difference between a fog seal and a rejuvenator seal is in the chemical make-up. An asphalt rejuvenator is a petroleum product based on maltene (lighter component of asphalt), whereas a fog seal is an asphalt-based emulsion. Normally rejuvenator seals, rather than fog seals, are used for more aged and ravelled pavements. Fog or rejuvenator seals with or without sand application on OGFC have diverse effects depending on the application rate, age and condition of the pavement.

Estakhri and Agarwal [15] suggested that a fog seal application rate of 0.05 gal/sy was not effective in reducing the aging rate based on limited data of HMA. Another study indicated a 30%

reduction of oxidation in HMA by an application of Gilsonite-Sealer-Binder (GSB) [17]. The stiffness and loss of surface fines in a high air-void-content mixture could be significantly reduced by the rejuvenators [15].

However, there are two trade-offs that must be considered when a fog or rejuvenator seal is applied on an OGFC surface. First, the seal will fill the surface voids and may reduce the drainage capacity of OGFC. Over time, the OGFC may become much like a dense-graded mix with little drainability and little reduction in splash and spray. Second, the seal may temporarily reduce the surface friction, or an inappropriate use of the seal may result in a slick surface [15]. If there is a significant loss in friction, the potential of reduced safety outweighs the benefits of applying the seal.

Owing to its numerous benefits, OGFC is being regularly used as the final riding surface on interstate and high-traffic expressways by different highway agencies in the United States, including the Alabama Department of Transportation. However, some OGFC sections have experienced premature failure due to ravelling only after 6-8 years of service life. Although surface distress is evident in all lanes, severe failure is more predominant in the outside lanes. An example of this surface distress is shown in Figure 1.

Figure 1. Ravelling in southbound outside lane at Milepost 177.9 (near Prattville)

The maintenance practices of OGFC pavements currently in vogue are not yielding effective results. The application rate of the fog and rejuvenator seals could be one of the probable causes of this issue. The objective of this study is to evaluate the effectiveness of the fog and rejuvenator seal application rates for the performance of OGFC in order to recommend an optimum application rate. The performance is assessed in terms of surface friction and durability.

MATERIALS AND METHODS

Methodology

The research methodology for evaluating the effects of using fog and rejuvenator seals on the performance of OGFC based on durability and surface friction is as illustrated in Figure 2. Three types of seal material were evaluated, namely two asphalt rejuvenators: Pavegaard (PG) and

Pavepreserve (PP), and a fog seal: a cationic slow setting (CSS-1H) asphalt emulsion [18-20]. These seal materials were obtained from Martin Company (Houston, Texas). Each material was applied at three different application rates. The evaluation was conducted through both the field work and laboratory testing. The former involved applying each fog seal material at a predetermined application rate on two OGFC test sections at the National Centre for Asphalt Technology (NCAT) pavement test track in Opelika, Alabama. Then the surface friction characteristics of treated and untreated OGFC surfaces were tested using a dynamic friction tester (DFT) and a circular texture meter (CTM). Cores were then cut from treated and untreated OGFC surfaces for laboratory testing, which included bulk specific gravity (Gmb) measurement, Hamburg wheel-tracking device (HWTD) test and Cantabro abrasion test.

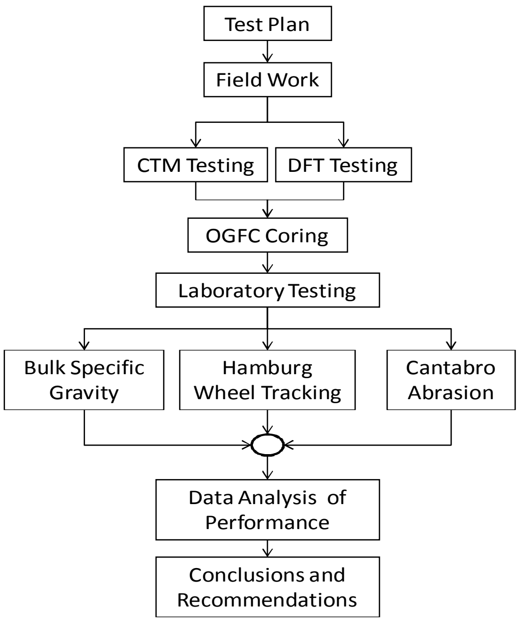

Figure 2. Steps for evaluating effects of fog and rejuvenator seals on performance of OGFC pavement

The test site, two sections (W4 and W5) on the inside lane at the NCAT pavement test track, was selected for field evaluation. The two sections were surfaced with two OGFC mixtures in 2000. The two OGFC mixtures used in sections W4 and W5 consisted of the same granite aggregate gradation (Table 1) and similar binder contents of 6.1% and 6.2% respectively. Modified binders of styrene butadiene rubber (SBR) and styrene butadiene styrene (SBS), which met the requirements of performance grade 76-22, were used in sections W4 and W5 respectively. The average thickness of the OGFC surfaces for sections W4 and W5 was 1.1 in. and 0.7 in. respectively, based on the thickness measurement of the cores extracted from the two sections. These sections were not trafficked regularly but were used for moving construction equipment during the construction, reconstruction and maintenance of the outside lane, which was trafficked during each research cycle. The site selection posed an inherent limitation as the effect of traffic on aging of asphalt binder was lacking in the real sense.

Table 1. Design gradation for OGFC mixture used in test sections W4 and W5

Sieve size, mm	Per cent passing by weight
19.00 (3/4 in.)	100.0
12.50 (1/2 in.)	95.0
9.50 (3/8 in.)	66.0
4.75 (#4)	23.0
2.36 (#8)	14.0
0.07 (#200)	8.6

Field Testing

Figure 3 shows the layout of test sections W4 and W5 containing squares (20x20 in. each) for evaluating the fog seal and rejuvenator seals as well as the type of fog/rejuvenator seal material and its application rate for each 20x20 in. square. In each square, a fog/rejuvenator seal material was evenly sprayed (Figure 4) at a predetermined application rate, and the surface was not sanded after the application because the fines from the sanding process might fill in the surface voids causing an adverse effect on the drainability of OGFC. To control the application rate, the sprayer was weighed before and during the spray application to determine the amount of fog/rejuvenator seal material applied in each square. In addition, a 2x2 in. geosynthetic pad whose weight had been predetermined was placed at the centre of each square during the spray application and then removed and oven-dried to a constant mass to determine the actual application rate of fog/ rejuvenator seal material for each square.

After the fog and rejuvenator seals had been cured for one week, the friction and macro texture characteristics of the OGFC surface in each square were measured by DFT in accordance with American Society for Testing and Materials (ASTM), Test no. E1911-09 AE01 [21] and by CTM in accordance with ASTM, Test no. E2157-09 [22]. After that, five 6-in. cores were taken from each square for laboratory testing.

Laboratory Testing

The five full depth cores (including the OGFC wearing course and the Superpave mixture in the underlying layer) taken from each square (except squares containing CSS-1H), shown in Figure 3, were used for further testing in the laboratory to determine the effects of the rejuvenators on the durability of OGFC. For each set of five cores, two cores were used for bulk specific gravity measurement and Cantabro abrasion test, two for HWTD test and one saved for future testing.

For bulk specific gravity measurement and Cantabro abrasion test, the OGFC surface layers were cut from two full-depth cores to prepare two test specimens. The bulk specific gravity of each OGFC specimen was determined using automatic vacuum sealing method in accordance with ASTM, Test no. D6752/D6752M-11 [23]. The specimens were then used for Cantabro abrasion test in accordance with Texas Department of Transportation standard [24].

For HWTD test, the top 1.5-in. layers including the OGFC wearing course and a part of the Superpave mix in the underlying layer were cut from two full-depth cores to prepare two test specimens. The two specimens were then used to run one HWTD test in compliance with American Association of State Highway and Transportation Officials (AASHTO) [25].

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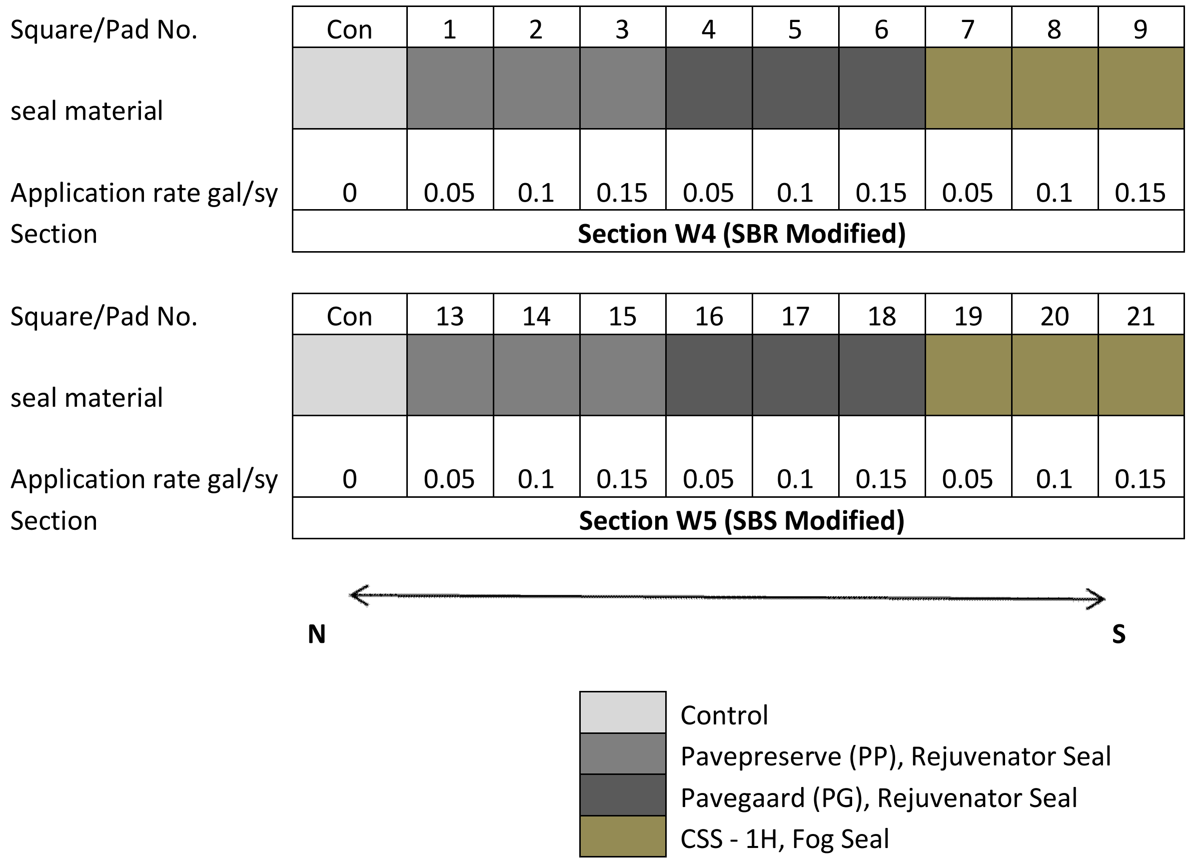

Figure 3. Layout of test sections for evaluating fog and rejuvenator seals

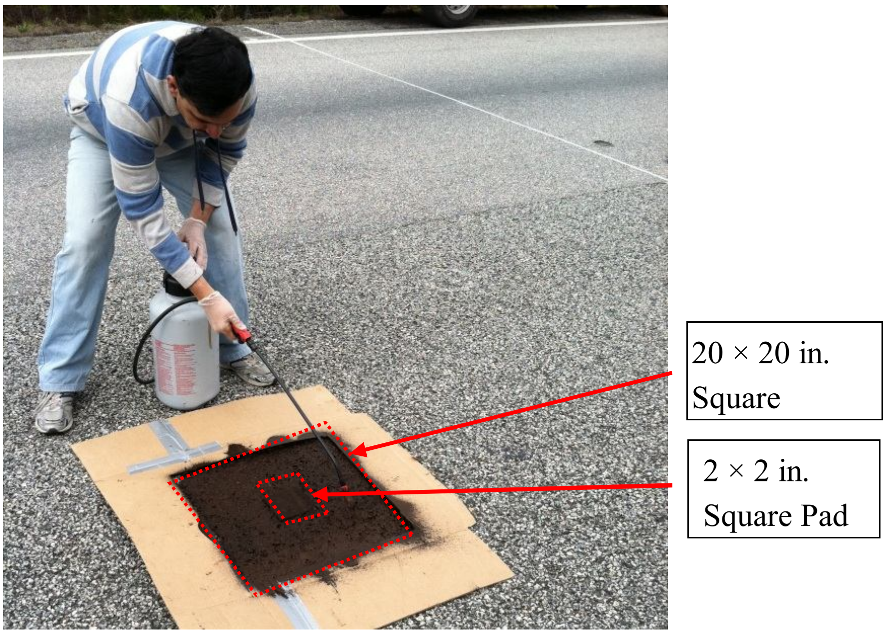

Figure 4. Spray application of seal material on OGFC pavement

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RESULTS AND DISCUSSION

Micro and Macro Surface Friction Characteristics

Analyses of CTM and DFT testing results were conducted to assess the micro and macro surface friction characteristics on application of fog and rejuvenator seals. The macro and micro texture analyses were conducted for the mean profile depth (MPD) obtained from CTM and friction number measured at 20 km/h (DFT_{20}) and at 40 km/h (DFT_{40}) using DFT. The international friction index (IFI) parameter F_{60} was calculated and analysed to find the mutual effect of macrotexture and microtexture of the pavement surface. The IFI consists of two parameters: F_{60} and speed constant (Sp). F_{60} is the harmonised estimate of the friction at 60 km/hr computed from both the friction measurement and Sp, whereas Sp is linearly related to macrotexture measurements. The IFI parameter F_{60} can be estimated based on DFT and CTM results using Equation 1 as given in ASTM E1960-07(2011) [26]:

$$F_{60} = 0.081 + 0.732 \times DFT_{20} \times e^{\frac{-40}{Sp}} \quad (1)$$

where:

F_{60} = international friction index
DFT_{20} = friction number obtained at 20 km/h using DFT
Sp = speed constant = 14.2 + 89.7 · MPD
MPD = mean profile depth obtained from CTM

Two analysis of variance (ANOVA) tests for all the measured MPD and DFT_{20} data were conducted. The results of these ANOVA tests at 95% confidence level ($P < 0.001$) show that the effect of the existing surfaces in sections W4 and W5 on the MPD and DFT_{20} measurements were statistically significant. Hence the effects of applying fog seal on the surface friction characteristics of OGFC were analysed separately for sections W4 and W5.

Figure 5 shows a graphical comparison of the effect of fog and rejuvenator seals on MPD for sections W4 and W5. ANOVA results indicate that the application of fog seal (CSS-1H) significantly affected MPD of the OGFC surfaces, especially at the medium and high application rates (0.1 and 0.15 gal/sy).

Figure 6 shows a graphical comparison of the effect of fog and rejuvenator seals on friction numbers for sections W4 and W5. ANOVA results show that the application of rejuvenator seals, especially PG for section W4, significantly affect DFT_{20} and DFT_{40}. For section W5, the application of fog seal and PG at low and medium application rates (0.05 and 0.1 gal/sy) significantly affected DFT_{20} and DFT_{40}. In the case of section W5, application of PP at high application rate significantly affected DFT_{20} and DFT_{40}.

Figure 7 shows the per cent decrease in IFI parameter F_{60} of OGFC due to the application of fog and rejuvenator seals for sections W4 and W5. The decrease in F_{60} depends on the type of modified binder used on the existing surface (W4 versus W5), the type of rejuvenator or fog seal material, and the application rate. The surface friction based on F_{60} was reduced 2-24%. Thus, fog and rejuvenator seals should be used with extreme caution on OGFC as they may cause a temporary loss of friction. Fog seal (CSS-1H) showed similar effects on the surface friction characteristics of the two sections. Rejuvenator seals (PG and PP) affected the surface friction characteristic of section W4 more than that of section W5.

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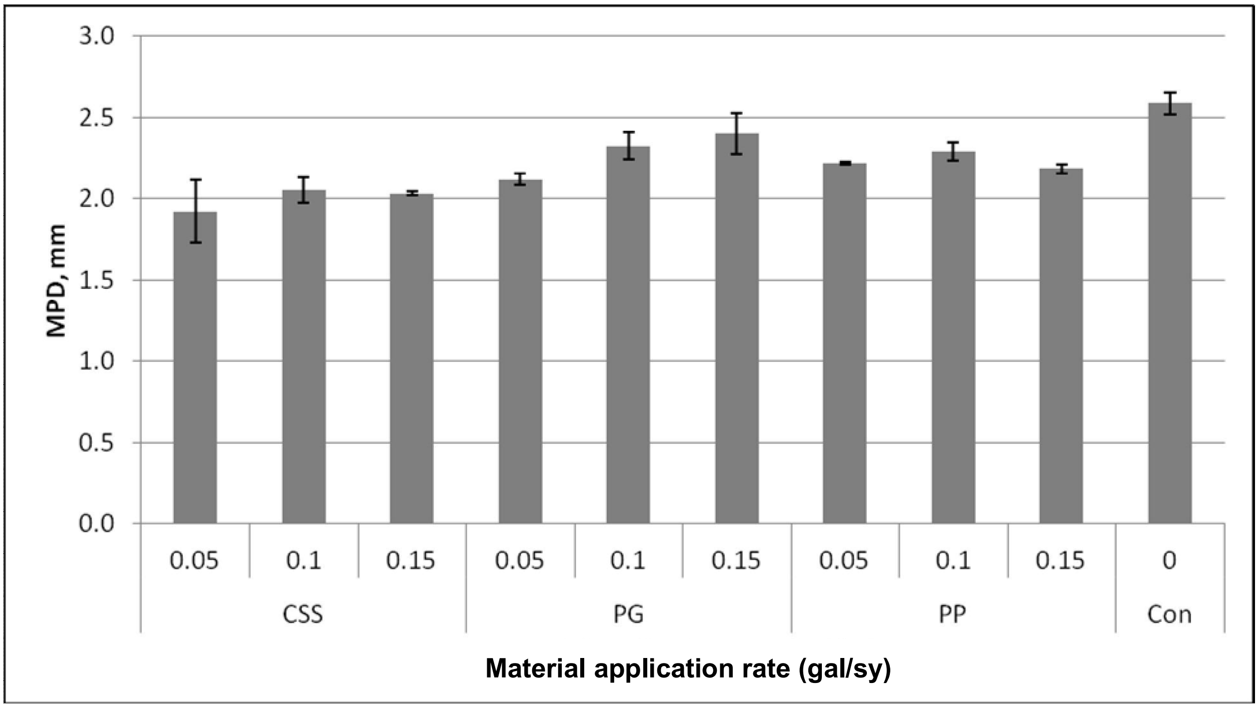
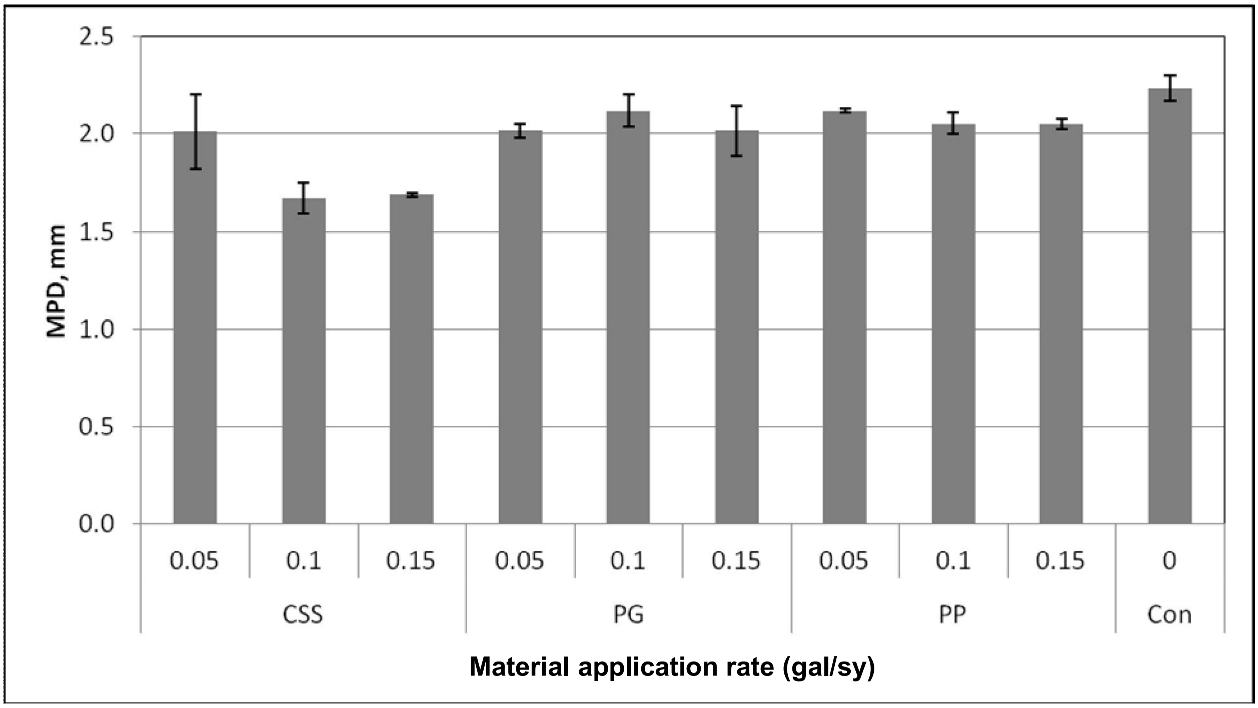


(a) Section W4



(b) Section 5

Figure 5. Effect of fog and rejuvenator seals on MPD for sections W4 and W5

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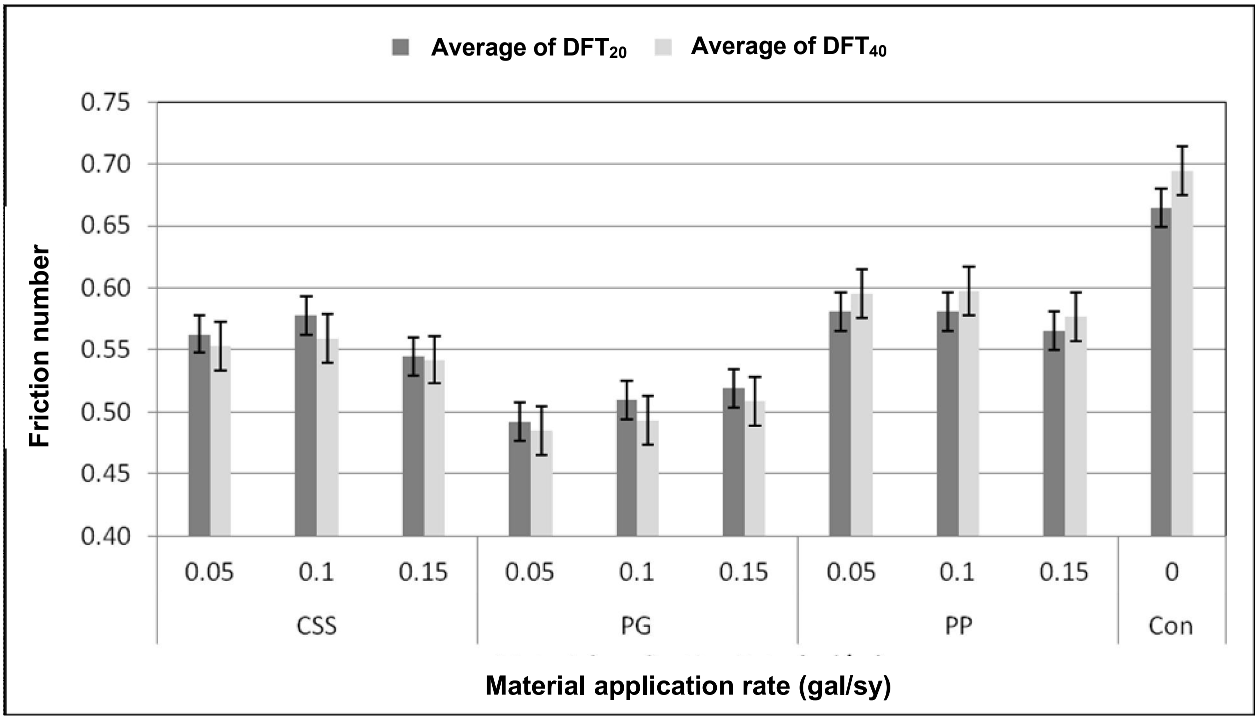
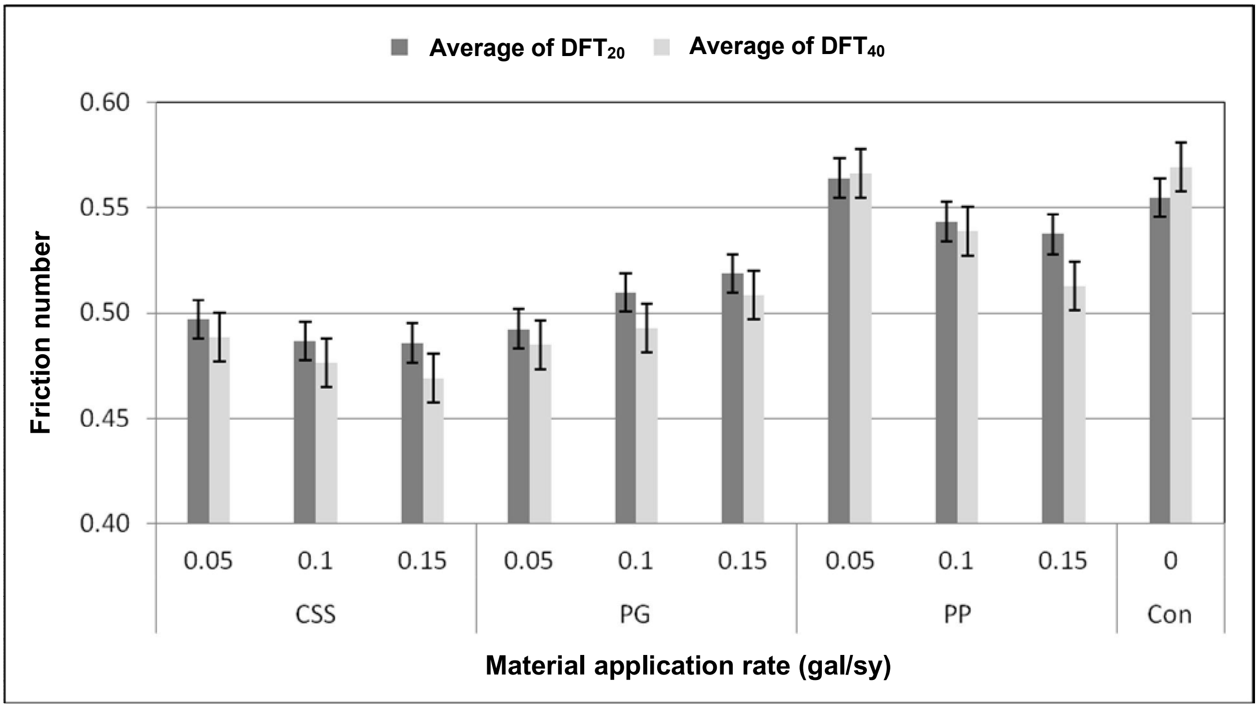


(a) Section W4



(b) Section W5

Figure 6. Effects of fog and rejuvenator seals on friction number for sections W4 and W5

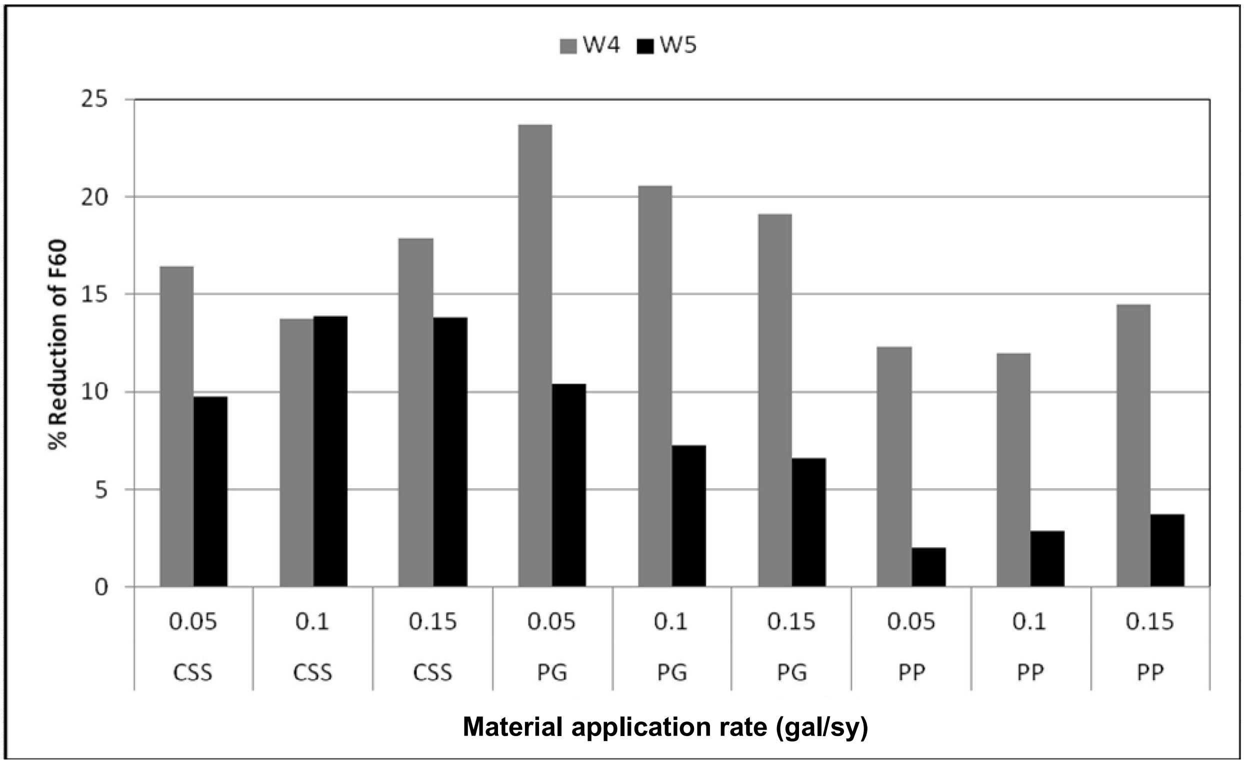


Figure 7. Per cent decrease in F_{60} due to fog and rejuvenator seals on OGFC

Air Void Measurement

Analysis of air voids was carried out to assess their impact on the functionality of OGFC on application of rejuvenator seal. ANOVA tests for all the measured air voids were conducted separately for sections W4 and W5. The results of the tests at 95% confidence level (P = 0.25 and R^2 = 39.04% for section W4, and P = 0.033 and R^2 = 58.08% for section W5) show that the differences in air voids were not statistically significant ($P > 0.05$) for section W4 while for section W5 the statistical significance ($P < 0.05$) was at the borderline.

Figure 8 shows the air void measurements for the control squares with no treatment and for other squares with the rejuvenator seals sprayed at 0.05, 0.10 and 0.15 gal/sy. A trend of reduced air voids with increase in rejuvenator seal application rate, resulting in reduction in functionality especially for section W5, can be observed. This is a matter of concern as the capacity to drain water through OGFC pavements would be reduced and the functionality of the mix would be affected.

Cantabro Test Results

The Cantabro test indicates the mixture resistance to wear and ravelling [6, 27] and is recommended for use in a standard OGFC mix design procedure based on previous NCAT research [7, 14]. This test has been used to predict the durability of OGFC pavements during their service life.

Analysis of Cantabro per cent loss was conducted to evaluate the improvement in resistance to wear and ravelling on application of a rejuvenator seal. ANOVA tests were done for all values of Cantabro per cent loss. The results the tests at 95% confidence level (P = 0.413 and R^2 = 50.21% for section W4, and P = 0.167 and R^2 = 65.03% for section W5) show that the Cantabro per cent losses

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were not statistically significant ($P < 0.05$) for sections W4 and W5, although they showed an intermediate existing relationship ($R^2 = 50.21\%$ for section W4 and $R^2 = 65.03\%$ for section W5).

Figure 9 shows the Cantabro loss results for OGFC specimens extracted from control squares and squares with the two rejuvenator seal products sprayed at the rates of 0.05, 0.10 and 0.15 gal/sy. The loss values were higher than what would be acceptable during mix design but they wee probably due to the age of the pavement and the thickness of the cores used for testing. Resistance to abrasion usually improves with an increase in binder content [3] and in this case each of the rejuvenator seal products appeared to improve the abrasion resistance. These results indicate that an application rate of 0.10 gal/sy or more should be suitable depending on the type of rejuvenator seal applied and the type of modified binder used on the existing surface (W4 versus W5) of OGFC pavement.

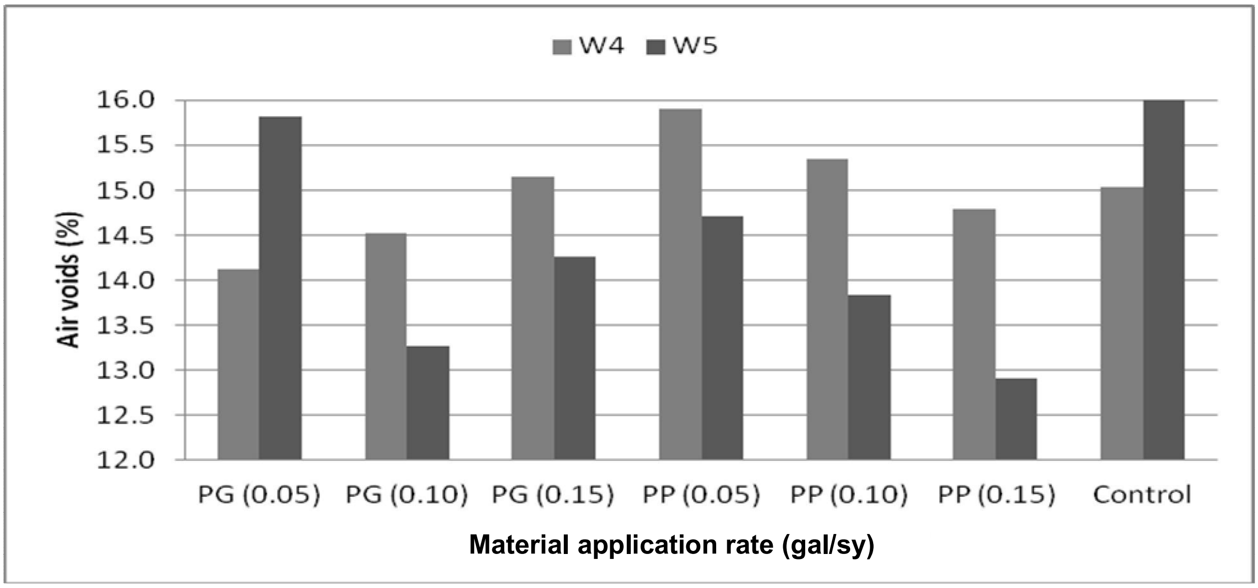

Figure 8. Per cent specimen air voids resulting from spraying with rejuvenator seals

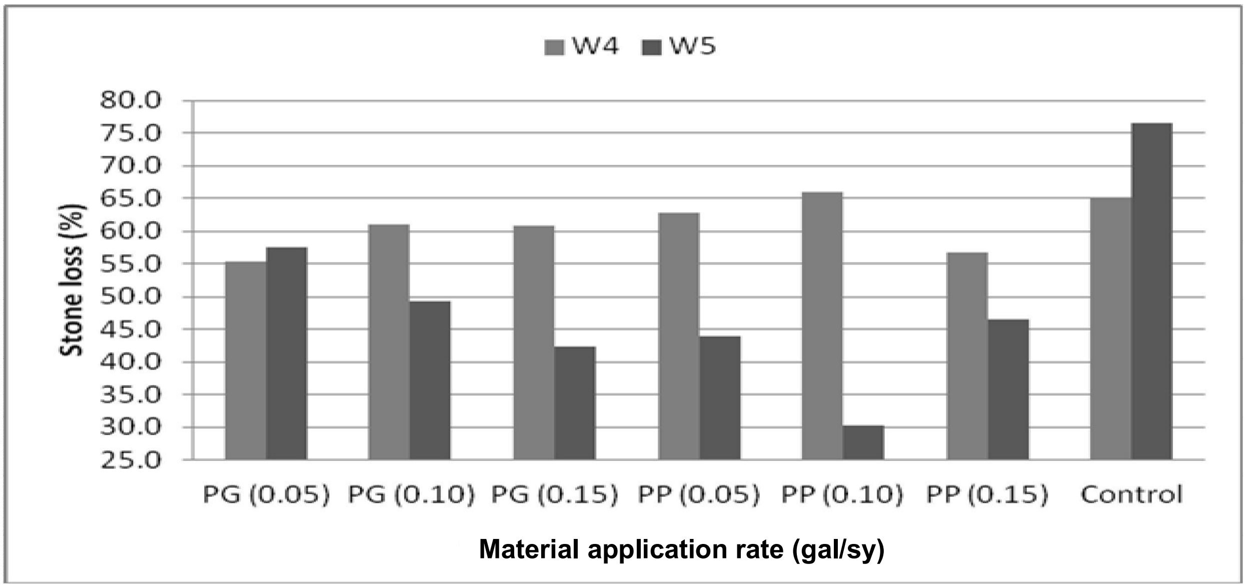

Figure 9. Effects of treatment type and application rate on Cantabro stone loss

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Hamburg Test Results

The Hamburg wheel-tracking device (HWTD) was introduced in the United States as a result of the 1990 European asphalt study tour [6]. Analysis of Hamburg rut depth was conducted to evaluate the improvement in resistance to rutting on application of a rejuvenator seal. ANOVA tests comparing the rut depth to material application rate were conducted together for sections W4 and W5. The results of the tests at the 95% confidence level (P = 0.047 and R^2 = 77.28%) show that the statistical significance (P < 0.05) of the rut depth for both sections was at the borderline, although there existed a strong relationship (R^2 = 77.28%).

Figure 10 shows the average rut depth of cores (using the Hamburg rutting procedure) from control squares and squares with the two types of rejuvenator seal (PG and PP) applied with three different application rates (0.05, 0.10 and 0.15 gal/sy). Contrary to all other laboratory test data, the HWTD test results clearly show a trend that the medium application rate (0.10 gal/sy) was better in enhancing resistance to rutting and/or moisture. Based on these results, it appears that the typical application rate of 0.05 gal/sy used in the past may not be adequate to improve resistance to rutting damage.

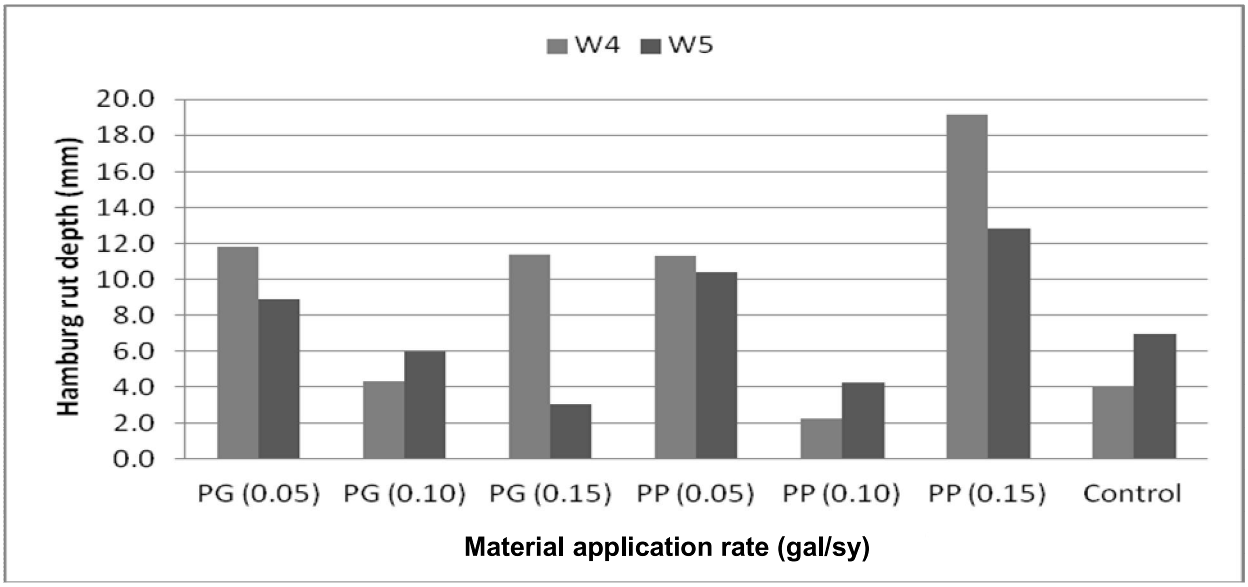

Figure 10. Average Hamburg rut depth after 10,000 cycles

CONCLUSIONS AND RECOMMENDATIONS

Fog and rejuvenator seals significantly affect the micro and macro texture of the OGFC surfaces in general. The surface friction may be reduced up to 24 per cent depending on the type of modified binder used in the pavement, the type of rejuvenator or fog seal material, and the application rate. Therefore, fog and rejuvenator seals should be used with caution on OGFC as they may cause a temporary loss of friction. A trend of reduced air voids was observed with increase in rejuvenator/fog seal application rates, which is a matter of concern as the functionality of OGFC mix would be affected. The Cantabro loss values were much higher than what would be acceptable for the OGFC mix design, but the probable reason for the high loss was the age and low thickness of the OGFC cores used for testing. The rejuvenator seals appear to improve the abrasion resistance. The Cantabro test indicates that an application rate of 0.10 gal/sy or more may be suitable depending on the type of rejuvenator being applied and the type of modified binder used in the pavement. Contrary to all other laboratory tests, the HWTD test results clearly show a trend that the medium application rate (0.10 gal/sy) is better in improving resistance to rutting.

In order to expand and further validate this research, it is recommended that the OGFC sections from lightly and heavily trafficked interstate highways are selected for study and monitoring of the effect of rejuvenator and fog seals. Other rejuvenator and fog seal materials should also be selected to broaden the scope and efficacy of the research.

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