A REVIEW OF PERFORMANCE CHARACTERISTICS OF OPEN-GRADED FRICTION COURSES (OFC) AND ITS APPLICABILITY IN SRI LANKA

by

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1.0 Introduction

As the mileage of high speed roads and traffic volumes on roads increased, traffic accidents causing severe injuries and fatalities too have increased in the last four to five decades all over the world. The reduction of the pavement surface friction became one of the major areas of research and development and the reduction of wet weather skidding became a primary concern in the US and Europe.

In the early stages of development, surface treatment methods such as seal coats, chip seals etc. were used to improve the surface texture of asphalt concrete (AC) pavements. In this method, after the application of asphalt cement over the base, cover aggregate [generally about 15mm (1/2 inch) top size] were spread and the surface was rolled to embed the aggregate. If this treatment is done properly, a good skid resistance surface course can be obtained. The main disadvantages of this method are: i) on high speed roads, the aggregate would become loose and this could damage windshields and headlights ii) the loss and polishing of aggregate would reduce the surface friction iii) sometimes it was necessary to close traffic lanes for a longer duration of time for aggregates to be properly rolled and cured, and iv) pot hole patching had been difficult in some cases.

In an attempt to obtain the benefits of the surface treatment friction courses and minimize the limitations and disadvantages, many countries in the world began to experiment with plant-mix seal coats. In this method normal chip seal aggregate is mixed with relatively high percentages of paving-grade asphalt cement in a hot-mix plant, and the mixture is placed with an AC paver at a thickness of about 20 mm (3/4 inch). The aggregate is essentially one-size. Therefore this treatment had a larger void ratio than conventional asphalt pavement layers. Since this treatment has the advantage of improved surface course friction without the disadvantages of conventional seal coats, chip coats etc., plant-mix seal coats were widely used in many parts of the world including Sri Lanka. In addition, this treatment method has the benefits of reduced splash and spray, noise and headlight glare. However, with the passage of time it was observed that there were construction difficulties on some occasions, maintenance problems, concern about long term performance, its inability to drain water quickly under heavy rainy conditions and low surface friction under wet conditions. The low surface friction under wet conditions became a major concern in Europe and US due to its high rate of accidents. In Sri Lanka too, many concerns were expressed in the newly rehabilitated trunk roads like Colombo-Kandy road (A1) as many accidents occurred supposedly due to low friction surface on certain sections, specially under wet conditions.

During the development stage of high friction surfaces by various highway agencies, a number of different methods and descriptive terminologies (plant-mix seal, popcorn mix, porous asphalt surface, open-graded friction course) were used.

The terminology Open-Graded Friction Course (OFC/OGFC) is used for all asphalt-aggregate pavement surface courses containing substantially larger percentages of voids than conventional asphalt concrete surfaces. The main objectives of the OFC are to improve pavement surface friction characteristics and thus to reduce wet weather accidents, but it includes other benefits like reductions in splash and spray, noise, and headlight glare during periods of rain. There is no clear-cut distinction between the conventional seal coats and the open graded friction courses with respect to their construction techniques and many performance records, except for the higher surface friction achieved specially during wet conditions.

The research and experimental work done in the United States and in european countries like Belgium, France, Italy, The Netherlands, Spain, Switzerland

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and the United Kingdom have found similar advantages and limitations, even though there are slight variations in the specifications, design and construction methods.

The AASHTO (1991) Report on the 1990 European Study Tour states that the Belgium Road Research Centre has conducted extensive research on OFC performance, design and construction and OFC are used on roads, airfields, and in tunnels. Current practice is to use about 22% voids and place the mixture at a compacted thickness of about 40 mm. In France and Italy, OFC are widely used in urban areas to reduce the noise level. In the Netherlands OFC are laid for over 100 Km per year in their motorways. The layer thickness is about 50 mm. The first application OFC in Spain was done in 1980 to improve traffic safety in areas of frequent rainfall. Beginning in 1986, OFC were widely used in Spain, and now the use has expanded to provide a smooth, safe, and quiet ride in any type of weather. Earlier applications used mixtures with 15 to 18% voids, but the current practice is to use mixtures with voids content over 25%. In the United Kingdom OFC were applied over 20 years ago, but the use has not been extensive.

This paper reviews the performance characteristics of Open-Graded Friction Course (OFC/OGFC) in the United States and Europe and discusses the applicability of them in Sri Lanka.

2.0 Factors Affecting the Performance of OFC

The main factors affecting the performance of OFC are :

1) Materials used in construction and the mix design
2) Condition of the underlying surface
3) The nature of the surrounding environment
4) Construction methods
5) Maintenance and rehabilitation measures

2.1 Materials Used in the Construction and the Mix Design

The selection of materials to be used in the construction and the design of open friction courses (hot and cold mixtures) are given in the US National Cooperative Highway Research Program* (NCHRP) Synthesis 49. It covers material requirements and mixture design. The detailed procedures for OFC mixture design are included as an attachment to the FHWA (S) Technical Advisory T5040.31, 1990.

The physical properties of coarse aggregate in OFC are the controlling factors with respect to the attainment and maintenance of high friction numbers and a low friction-number speed gradient. It recommends the use of high quality, polish resistant aggregate with at least 75 percent by weight of coarse aggregate having at least two fractured faces, and 90 percent with one or more fractured faces. The recommended gradation is given in Table 1.

Table 1 - FHWA Recommended Gradation

US Sieve Size	Percent Passing (by weight)
1/2 inch	100
3/8 inch	95 - 100
No. 4	30 - 50
No. 8	5 - 15
No. 200	2 - 5

One of the basic requirements of OFC is that the final mixture after compaction have adequate void capacity to serve as lateral water drainage channels during rainstorms. Such channels also must have adequate capacity to handle normal rainfall without flooding. the property of the mixture is attained by the compactability of coarse aggregate, which in turn is primarily a function of the particle shape and crushed faces. the interstitial voids of the aggregate must be large enough to accommodate the total volume of asphalt plus the volume of fine aggregate and still leave adequate void space in the completed mixture. The FHWA procedure assumes that 15% design voids is minimum. The optimum amount of fine-aggregate fraction is that which permits the required quantity of the interstitial (coarse aggregate) voids to remain unfilled after the total volume of the asphalt cement and fine aggregate is added. The percent of fine aggregate (material passing the No. 8-2.36mm sieve) needed to assure the attainment of a minimum air-void ratio content of 15% in the compacted mixture. The amount of fine aggregate added must be less than 15%.

The recommended grades of asphalt cement are AC-10, AC-20 and AC-40. The AC-40 is recommended for pavements subject to high temperatures. Therefore in Sri Lankan context AC-40 has to be used.

The optimum mixing temperature is based on the concept that the aggregate should be reasonable dry to facilitate coating and adhesion yet not to be so hot that the viscosity of the asphalt binder is reduced to a level that causes drainage and segregation of the asphalt from the aggregate during the transit from the mixing plant to the job site. According to FHWA, the recommended mixing temperature is obtained by conducting a laboratory test and determining a suitable temperature for a asphalt cement viscosity in the range of 700 to 900 centistokes.

A review of literature on construction materials and mix design methods in the US and Europe reveal the following;

a) Many states in the US use a nominal top size of 3/8 in (9.5 mm) and 35 of the 40 typical gradations reported fall within the master range recommended by Federal Highway Administration (FHWA).

b) Some states in the US keep the fine aggregate fraction at a minimum to preserve the openness of the surface under traffic, whereas others accept the premise that sufficient fine aggregate must be present to provide a chocking action for the larger stones and consequently to create greater stability and holding power.

c) One basic requirement for OFC is the availability of high-quality non-polishing aggregate. A high friction number cannot be maintained with aggregates that do not have adequate microtexture and resistance to polishing and degradation under traffic.

d) A research and development project initiated by the Ministry of Transportation in Ontario, Canada in 1977 to determine more economical friction course mixes for locations other than heavily trafficked high-speed freeways, without resorting to the use of scarce, premium quality aggregates, found that imported premium quality aggregates (e.g. Maple Ridge or Havelock) can significantly improve the performance of surface friction courses when used along with locally available aggregates, and that open-graded mixes employing 100 percent of local aggregate (limestone, natural sand) did not perform satisfactorily in terms of friction or durability. OFC mixes containing about 65 percent of coarse aggregate in total aggregate mix, at least 25 percent of high quality coarse aggregate in total aggregate mix, and washed screening performed the best. It also recommended that the use of all soft limestone aggregates in both the coarse and fine aggregates be avoided. However, if this is not possible, a mix should contain at least 25 percent of blended crushed hard-rock coarse aggregate (.4.75mm) in the total mix in the course fraction.

e) Durability is influenced primarily by asphalt cement film thickness and asphalt-aggregate resistance to stripping in the presence of moisture. A film thickness of 8 to 11 microns is recommended. Because the high voids content increases potential for stripping, the mixture should be tested for moisture susceptibility and, if necessary, anti-stripping additives are used as appropriate.

f) Hydrated lime has been found to be effective in reducing stripping potential of OFC mixtures and is required by the New Mexico State Highway Department (NMSHD) specifications for construction of such pavements.

g) It has been observed that on multilane roadways, the 20mm (3/4 inch) thickness of OFC with air voids of 12-15 percent generally used in the US is likely to become flooded during moderate to heavy rain. The European and Oregon Department of Transportation (in the US) experience with thicker OFC surfaces and higher void contents demonstrates that such surfaces can be built and maintained. These thicker surfaces appear to improve noise reduction capabilities as well as internal drainage. With the use of thicker OFC surfaces, there should be consideration of the structural value contributed to the pavement. It is apparent that a single OFC mix design, specifically percent air voids and surface thickness, would not be optimum for all traffic volumes, climatic conditions and roadway types.

h) In Europe OFC mix designs have void contents of up to 25 percent, layer thicknesses of 40 to 60 mm (1.5 to 2 inches), and additives including polymers and cellulose fibers are used to produce increased binder film thicknesses. This had been found very successful.

i) One of the more serious causes of the early failure of OFC is the oxidation and hardening of the thin binder films on the coarse aggregate. The combination of European research and experience with additives to increase binder film thickness and the research conducted by the Strategic Highway Research Program (SHRP) on the use of additives to improve the performance of asphalt cement should be very helpful in solving this problem.

2.2 Condition of Underlying Surface

a) OFC should not be used directly over structurally inadequate pavements. Little structural strength is added with OFC, and a pavement in structural distress must be upgraded or rehabilitated prior to the application of OFC.

b) It is necessary to correct any serious deficiencies of the existing pavement before applying OFC, A dense, impermeable surface requires only a tack coat. If the old pavement is dry, porous, and permeable, a prime coat may be needed. If the pavement is flushed, it may be necessary to remove the excess asphalt or take other measures to prevent such excess asphalt from bleeding through the new surface.

c) Open graded courses should not be used to correct severe rutting or depressions in the underlying pavement. Such action would create a basin for the accumulation of water which would eventually seep into the base and accelerate structural damage to the pavement.

d) Movement within the underlying pavement or base would result in rutting of pavements overlaid with OFC or dense-graded surfaces.

e) Reflection cracking occurs faster under certain conditions - problems have been particularly bad for overlays over portland cement concrete. Raveling also occurs at the cracks.

f) OFC should be placed on a structurally sound AC paved surface. Existing portland cement concrete (PCC) pavements must be overlaid with some type of AC course that has been sealed at the surface to provide lateral drainage of water as it passes through OFC. Existing AC pavements should be resurfaced or milled to provide a structurally sound pavement free of ruts, potholes and cracks, and sealed at the surface prior to the placement of an OFC.

g) OFC should not be placed directly over an existing PCC pavement because it is difficult to establish an adequate bond between thin OFC and the PCC surface. Lateral tyre forces will result in bond failure and loss of OFC.

h) Since the sealant beneath OFC is not 100 percent impervious, use of local aggregates susceptible to water-induced stripping leads to deterioration of the underlying layers. This problem is alleviated in some states in the US by using anti-stripping material (like lime) in preparing the mix for underlying layers and increased emphasis on placing a high quality sealant.

2.3 The Nature of Surrounding Environment

OFC are used on highways to provide adequate wet-weather skid-resistance. Therefore, OFC are not generally used in dry climates as it may not be cost effective. However in drier climates where surface oxidation or drying out is the most prevalent type of deterioration, the open friction course does provide a sealing action to prevent raveling of the previous surface.

2.4 Construction Methods

a) In the US, the mixture design and construction techniques (hot mixtures) are given in NCHRP Synthesis 49.

b) From a geometric standpoint, a pavement cross slope of at least two percent usually is necessary to ensure the effectiveness of OFC under all but low intensity rainfall. The OFC should be placed full width of the pavement and extend at least 3 ft. onto the shoulder to drain surface water away from the traffic lanes and to maintain uniform surface texture.

c) European experience indicates that thickness of the OFC should be a special consideration for multilane pavements and where abatement of traffic noise is a primary objective. When three or more lanes slope in the same direction, 20 mm (3/4 inch) OFC can become folded in all but low intensity rainfall, resulting in reduced effectiveness. In Europe it has been found that OFC up to 50 mm (2 inches) thick provide improved surface drainage and reduced traffic noise compared with the more conventional 3/4 inch thickness used in the US.

d) Other construction considerations include placing OFC only when underlying surface and ambient temperatures are above 60^oF (16^oC), limiting handling and hauling to 65km (40 miles) or 1 hour to prevent drain down of asphalt, and controlling compaction to avoid aggregate crushing and reduction in voids content. The mixing temperature is an important factor as it effects the mixture constituents. Placement at temperatures below 60^oF (16^oC) can lead to poor adhesion and subsequent bond failure. Placement at ambient temperatures above 100^oF (38^oC) may lead to non-uniformity and flushed areas in the finished pavement because of excess asphalt flow in the haul trucks or pavers.

e) In high rainfall areas where water infiltration into the base could create structural weaknesses, independent sealing with dense mixtures should precede the construction of the open friction course.

2.5 Maintenance and Rehabilitation Measures

a) Experience with the use of fog sealants to deter asphalt cement hardening has been mixed. Some agencies continue the practice but the Florida Department of Transportation in the US (a major OFC user) has not found fog sealants to be effective in extending OFC service life.

b) A primary concern of maintenance personnel is the need for patching OFC because of petroleum spills, depressions resulting from snow plow activity and other equipment, and local areas of bleeding and shoving. Use of available dense-graded patch material is generally required, at least as a temporary patch. But the desirable practice should be to patch these areas with OFC mixtures when such material is being produced in the area for a construction project.

c) Maintenance personnel should be aware of the need to preserve the lateral drainage capability of OFC. Consequently, the edges of patches should not be sealed and shoulders along OFC should not be resurfaced or sealed in a manner that will disrupt the lateral drainage. Cracks and joints should not be sealed in a manner that will deter the lateral movement of water through the OFC. Only transverse cracks and joints should be sealed.

d) currently available information indicates that an open-graded friction course is likely to have a service life of 8 to 12 years. Replacement of the surface may be required even though the pavement is structurally adequate. Studies suggest that the new OFC or dense-graded AC surfaces should not be placed on deteriorating OFC.

e) The practices currently preferred for rehabilitation of OFC at the end of their service life are:

i) mill off the OFC with equipment that will produce a smooth surface, place a seal/tack coat, and place the new OFC;

ii) mill to just below the existing OFC, place a dense-graded AC course of about 40 mm (1.5 inch) thickness, place a seal/tack coat, and place new OFC;

iii) mill to 40 to 50 mm (1.5 to 2 inches) below the existing OFC, place a dense-graded AC course of the desired thickness for structural adequacy, place a seal/tack coat, and place new OFC. The material provided by milling can be used as recycled asphalt pavement (RAP) but should not be used in the new OFC.

f) When the rehabilitation of a deteriorated PCC pavement includes an asphalt concrete (AC) overlay, OFC can be used as final wearing courses over other AC layers.

In addition, there can be failure due to closing up of the surface and loss of permeability to water. The European approach in dealing with this problem is to provide high initial void content.

3.0 Advantages and Limitations of OFC

The existing literature and reports on characteristics of OFC give the following advantages:

a) Hydroplanning potential during rainstorms in minimized. This is the main advantage of the OFC. The open-graded friction course provides drainage channels so that water flows from the surface below the highest aspirates of the aggregate. Consequently, good tyre-pavement contact is maintained in the presence of large volumes of water.

b) As seen in Fig. 1, the skid resistance at high speeds during wet weather is improved. Due to the macrotexture of OFC, the friction numbers of such surfaces do not decrease as rapidly with increasing speed as do the friction numbers of dense-graded surfaces.

c) Splash and spray during wet weather is minimized. In OFC, most of the water flows below the highest points of the surface and goes down the surface rather than laterally as in the case of dense-graded surfaces. Therefore, there is less water between the tyre and the pavement.

d) There is less glare and better visibility of road markings at night during wet weather. Because most of the water flows below the surface, the mirror effect of the water film that occurs on the surface of dense-graded pavements does not take place in OFC.

e) Wheel path rutting is minimized. The stability of OFC depends on the interlocking of its aggregate and its thickness is about 20 mm (2/4 inch). Therefore, there is no visco-elastic flow in the surface layer.

The limitations of OFC are :

a) Reflection cracking occurs faster under certain conditions. OFC overlays over portland cement concrete have particularly given rise to reflection cracking. Ravelling too have occurred often at these cracks.

b) Petroleum product spills cause rapid deterioration of the materials. Due to its open texture, this is an inherent property of OFC. Therefore, at places where there is a likelihood of petroleum spills, it is recommended to use a dense material.

c) The expected service life may be shorter than that of dense pavements. In many parts in the US and in Europe it has been reported that hardening of asphalt occurs faster in OFC than in dense grade surfaces. However, there is no convincing data and information to support this idea.

d) Patching is more difficult and preventive maintenance is necessary. This is a recognised disadvantage by many countries.

e) Provision must be made in the shoulder area to allow free flow of water collected in the OFC. This is not necessarily a disadvantage, but an important design consideration.

f) Costs per ton of OFC are generally higher than dense-graded mixtures. This may lead to higher total project cost. OFC has a greater coverage of surface area for a given weight because of its higher void content and a thinner course required when compared with dense-graded courses. These two factors offset the higher cost of OFC per ton to a great extent.

4.0 Discussion and Applicability of OFC in Sri Lanka

The increase in OFC use in both Europe and US indicates that this type of surface treatment is a successful technology. Literature review indicates that the advantages of OFC outweighs the limitations and problems in many instances. The research and experience in Europe and US reveals that the areas of design criteria (including percent of voids and thickness) and binder properties requires further studies and investigations. It has been proven that a single OFC mix design, percent of air voids, and surface thickness, would not be optimum for all traffic volumes, climatic conditions (rainfall, temperature etc), and roadway types. Each country has to evolve its own specifications, based on these factors.

The use of OFC is not a low cost surface treatment method as it has to be laid on structurally sound pavements and specific construction materials have to be used. Since it uses less asphalt cement compared to conventional plant-mix design to obtain a higher percent of voids, the cost can be lower in countries like Sri Lanka, where asphalt cement is expensive. The main reason for using the OFC is to improve the surface friction during wet conditions. Therefore this treatment becomes very cost effective for high speed (with operating speeds over 60 to 70 kmph) roads in wet zones with fairly large traffic volumes (Average Daily Traffic over 1000 vehicles) with reported high accident rates.

As indicated above provision must be made in the shoulder to allow free flow of water collected in the OFC. At least 1 m (3ft) shoulder width is required for this purpose. Also, it is important to note that OFC should not be used on road sections where there is a likelihood of oil spills from vehicles etc., as OFC will disintegrate very fast in the presence of these solvents.

Sri Lanka has embarked on a major rehabilitation program to improve the trunk road system. Research, experimental work and the past performances of Open Graded Friction Courses (OFC) in economically more developed countries (specially in the US) show that, this surface treatment method can be effectively used in hot climate countries such as Sri Lanka with heavy rainfalls. Many sections of Sri Lankan trunk roads like Colombo-Kandy (A1), Colombo-Galle (A2) etc. carry high traffic volumes. Most of these roads are not very well lit and there is excessive wet pavement glare at night. Even though there is no data and information to confirm that many accidents take place during wet weather conditions on the newly rehabilitated trunk road system, which has used conventional plant-mix surface treatment methods, there is a general perception among many road users that these roads are slippery during wet conditions. In view of the experiences in other countries and some concerns regarding the performance of conventional plant-mix surface treatment on Sri Lanka roads as well, it is worthwhile for highway agencies like the Road Development Authority (RDA), Road Construction & Development Company (RC&DC) etc. to experiment and study the performance of the OFC surface treatment method on relevant sections of the major arterial/trunk roads.

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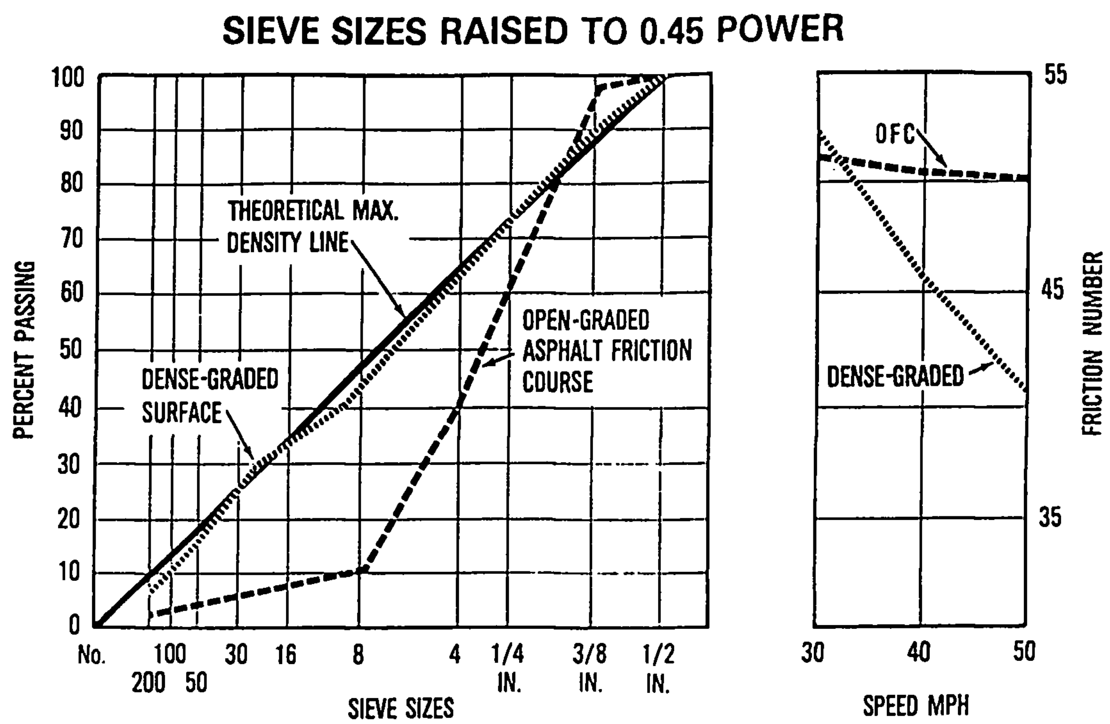

Figure 1 - Comparison of friction-number gradient of dense-graded mixtures and open-graded mixtures (FHWA).