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Review

An overview on the use of geosynthetics in pavement structures

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Pavement structures commonly fall into two main categories, namely, flexible and rigid pavements. Such structures just as other structures are susceptible to different types of distresses. In order to minimize the deterioration of pavements, geosynthetic reinforcement is one of the techniques adopted to improve their performance. As a result, employment of different geosynthetics to pavement structures is reported by various researchers. This paper aims to present and discuss the findings from some of the studies on utilizing geosynthetics in flexible pavements. Furthermore, three most common usages of geosynthetics, so called, fluid barrier, strain absorbing, and reinforcement agent in pavement structures are investigated in this paper.

Key words: Pavement deterioration, geosynthetics, pavement reinforcement, cracks, rutting, durability.

INTRODUCTION

Constant increases in traffic frequency and axle loads place great demands on the existing road network. The horizontal stresses induced between layers soon result in crack formation, and any local differential settlements also lead to cracking of the asphalt layer. These stresses result in crack formation caused by horizontal forces and by local differential settlements. Reinforcement of asphalt mixes is one approach taken to improve pavement performance. Reinforcement generally consists of incurporating certain materials with some desired properties within other material which lack those properties (Mahrez et al., 2003). The principal functions of reinforcement in asphalt concrete is to provide additional tensile strength in the resulting composite, by increasing the amount of strain energy that can be absorbed during the fatigue and fracture process of the mix (Mahrez et al., 2005).

Asphalt reinforcement using geosynthetic has received considerable attention by road authorities as viable solutions to enhance flexible pavement performance. Geosynthetic reinforcement is simply embedding oriented geosynthetic materials in the pavement structure (Abtahi et al., 2009). The introduction of this technology to the transportation industry was mainly prompted by the unsatisfactory performance of traditional road materials exposed to dramatic increases and changes in traffic patterns, a need that still exists.

Paving synthetics in asphalt and concrete overlays were first tested in the 1960’s with Geotextile (paving fabric). Regular testing and usage of paving fabric began in the mid 1970’s. The test reports and numerous test sections conclusively proved its value. Since then usage has increased to over 100 million square yards annually in the United States and maybe double that worldwide according to the Industrial Fabrics Association (Barazone, 2010).

Paving grids and composites were first used in Europe in the early 1980's and in the late 1980's in North America with the addition of a grid composite, grid and fabric. Grid usage is slowly growing and is now in the millions of square yards. Testing began on paving grids and composites in the early 1990’s and the results are just becoming available (Barazone, 2010).

TYPES AND CLASSIFICATION OF GEOSYNTHETICS

Geosynthetic is a planar product manufactured from a variety of synthetic polymer materials that are specifically fabricated to be used in geotechnical, geoenvironmental,

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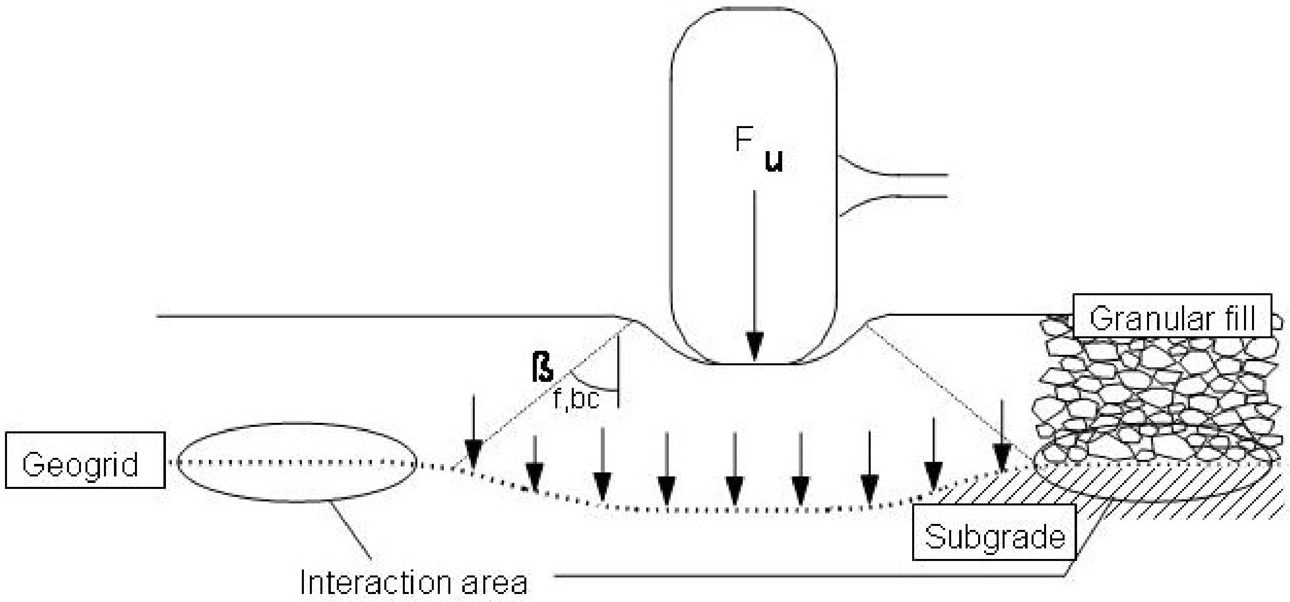

Figure 1. Unpaved road design model (Elias, 2004).

hydraulic and transportation engineering related materials as an integral part of a man-made project, structure, or system (ASTM, 2000). They usually consist of seven main categories named geotextiles, geogrids, geonets, geomembranes, geosynthetic clay liners, geofoam, and geocomposites. When it comes to soil and asphalt pavement reinforcement, out of seven categories geotextiles, geogrids and geocomposites are the ones usually utilized. The range of the geosynthetic layer thickness underneath asphalt overlays is 25 to 100 mm of AC or Portland cement concrete (PCC) (Hosseini et al., 2009).

DESIGN PRINCIPLES OF GEOSYNTHETIC FOR ROADS

During construction of roads on soft soils a certain bearing capacity of the subbase is required to prevent unnecessary differential settlements of the road structure. For subsoil with insufficient bearing capacity, stabilization is necessary. The bearing capacity can be increased by excavation of the soft material, chemical stabilization by using chalk or by using geosynthetics. When using geosynthetics in paved road structures (surface layer existing of asphalt or concrete) the long term behavior has to be taken into account. The measures bearing capacity on top of the base should be maintained during the total service life of the road (Meyer and Elias, 1999).

Existing design methods for flexible pavements reinforced with a geosynthetic in the unbound base aggregate layer are largely empirically based (Berg et al., 2000). These existing design methods have been limited in use by many state departments of transportation due to several factors, namely:

1. Design methods are not part of a nationally recognized pavement design procedure.
2. Design methods are often times applicable to a narrow range of design conditions.
3. Design methods are often times proprietary, making it difficult to directly compare the cost-benefit of several reinforcement products from different manufacturers

Design philosophy

Several design philosophies have proven themselves over the past years. The first philosophy is for the unpaved road, the second philosophy is for the paved road situation.

The design for a paved road starts with the unpaved situation during construction and only then goes on to consider the paved situation. It therefore integrates the results of calculation for the unpaved road with those for the paved structure (with asphalt or concrete).

Unpaved roads

The unpaved reinforced road design philosophy is based on the membrane method (Giroud and Noiray, 1981). When some small rutting appears the reinforcement is acting as a membrane which creates tension. This tensioned geogrid membrane will create an upward force to resist further rutting at the top of the surface (Figure 1). The stiffness of the geogrid reinforcement is an important input parameter. Special design tools are available in the market to calculate the minimum thickness of the road foundation for unpaved roads (Elias, 2004).

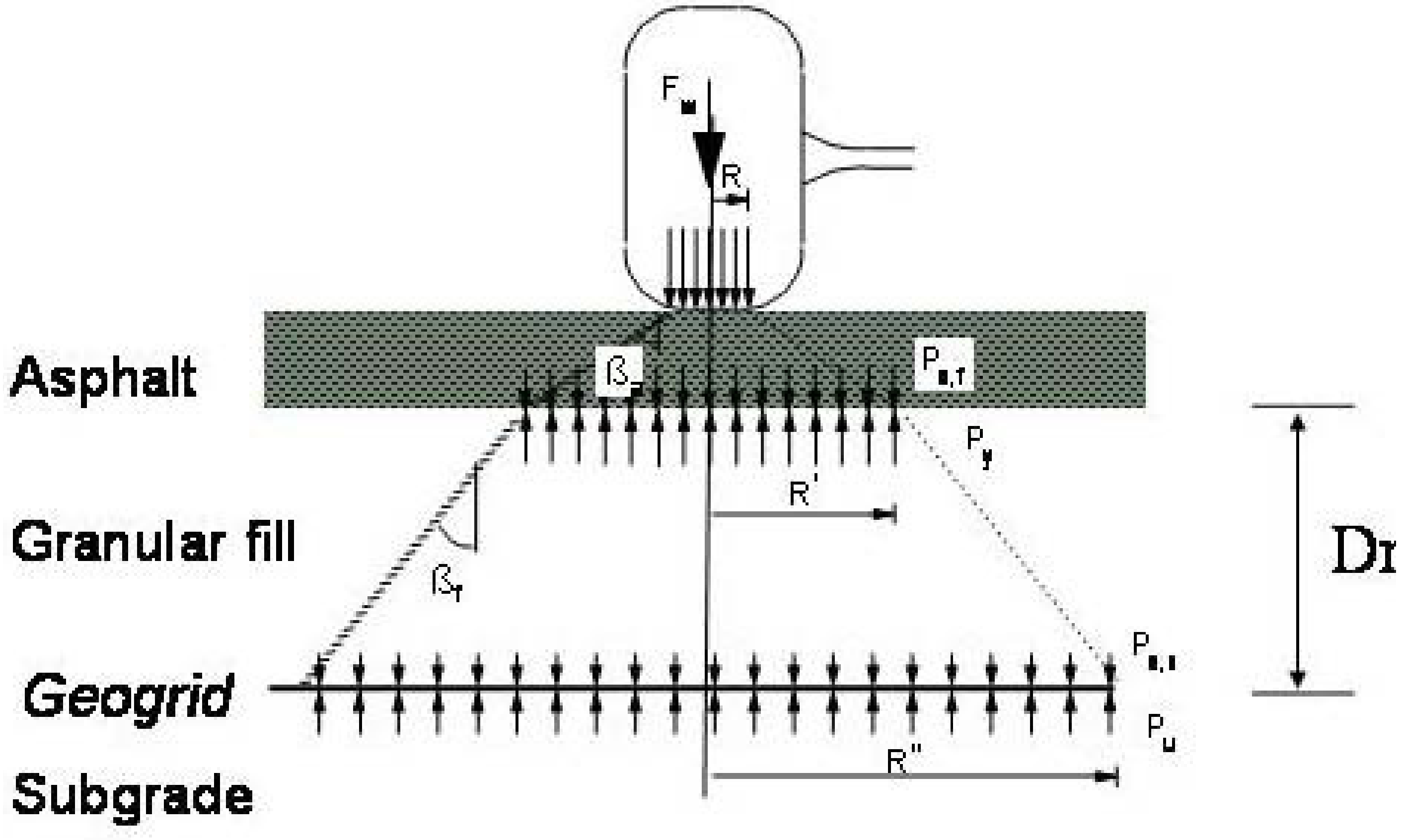

Figure 2. Paved road design model (Elias, 2004).

Paved roads

For paved roads, the available method is based on the combination membrane method (Giroud and Noiray, 1981) and the bearing capacity method (Hously and Jewell, 1990; Meyer and Elias, 1999). The wheel load is spread down through the road foundation. The stiffer the foundation layer, the more load spreading will appear. Using geogrids will increase the stiffness of the foundation and therefore will also increase the load spreading (Figure 2). The bearing capacity of the soil is calculated based on the CBR value. This bearing capacity is checked with the load on top of the soil. When the bearing capacity is higher than the load, the factor of safety will be greater than 1.0. Similarly, the same method can be used for the bearing capacity of the base and subbase layers (Elias, 2004).

EFFICIENCY FACTOR OF GEOSYNTHETIC AS REINFORCEMENT

The efficiency of the geosynthetics as reinforcement in a pavement (Palmeira, IGS) can be estimated by the efficiency factor (E):

$$E = \frac{N_r}{N_u} \tag{1}$$

N_r = number of load repetitions up to failure for the reinforced pavement.

N_u = number of load repetitions up to failure for the unreinforced pavement.

Available data in the literature present values of E as high as 16, which shows that considerable increases on the pavement lifetime can be achieved with the use of geosynthetic as reinforcement or separation. Field observations and research results confirm the improvements of pavement performance due to geosynthetic utilization (Palmeira, IGS) (Figure 3)

FUNCTIONS OF GEOSYNTHETICS

It is convenient to identify the primary functions of a geosynthetic when used in general engineering applications as being one of: separation, filtration,

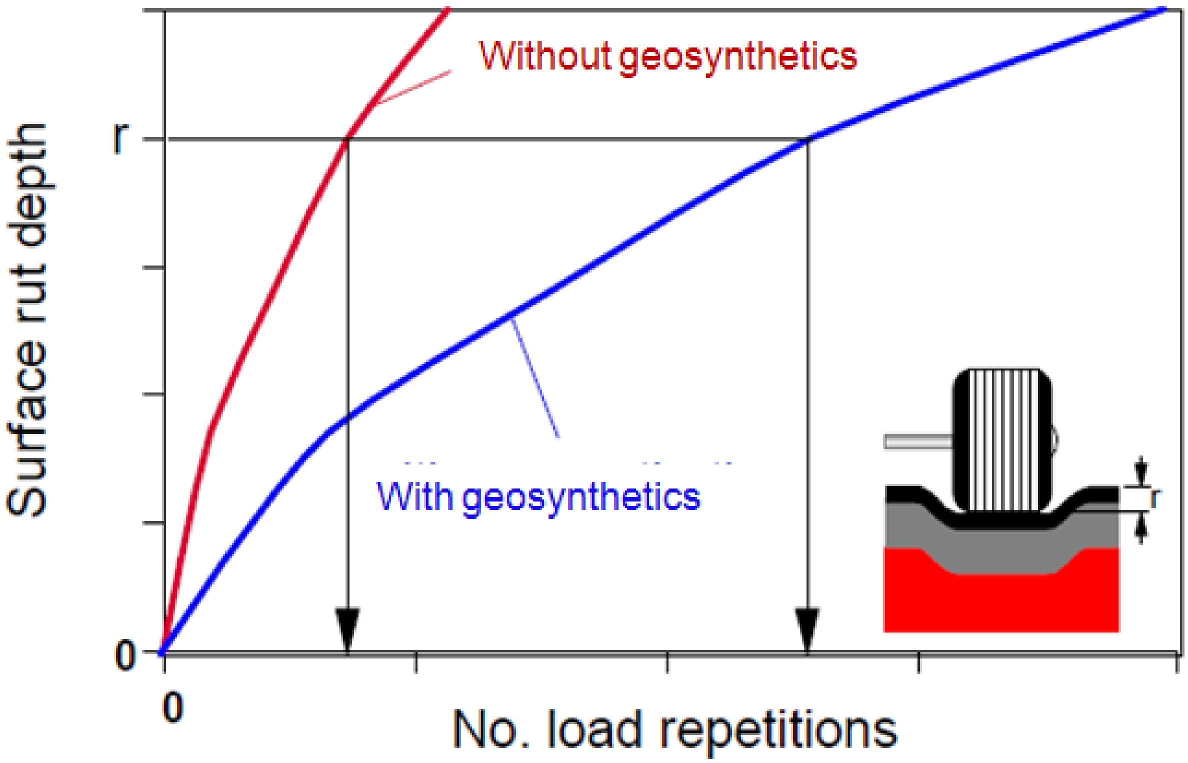

Figure 3. Increase of pavement life time due to the use of geosynthetic reinforcement (Palmeira, IGS).

drainage, reinforcement, fluid/gas containment, or erosion control. In some cases the geosynthetic may serve dual functions. The major functions of geosynthetic materials in relation with transportation engineering are separation, reinforcement, filtration, drainage and acting as a liquid barrier (Khodaii et al., 2009), but in the asphalt layer if properly installed they mainly function as fluid barrier, cushion, and reinforcement.

Fluid barrier (undersealing)

One of the functions geosynthetics possess is that they can act as a means to prevent moisture from infiltrating into the pavement structure, and such waterproofing action may limit base and subgrade movement due to freeze-thaw action or expansive soils (Button and Lytton, 2007), consequently, delaying the deterioration of the pavement structure. For example, if geotextiles are impregnated with bitumen, they are able to protect the underlying layers from degradation (Hosseini et al., 2009). Given that the fabric is saturated with sufficient asphalt to provide a continuous moisture barrier, fabrics may remain intact even after the asphalt overlay has cracked and provide a moisture barrier. However, if a moisture barrier is justified, fabrics and composites offer this added benefit but grids cannot (Button and Lytton, 2007). One of the factors that may influence this action is rate and amount of tack coat application. The results of a research showed that the slight excess of tack coat is believed to assist in waterproofing the fabric from the infiltration of water in the event that a crack reflects through to the surface (Lytton, 1989). As a result, geosynthetics may be used to limit base and subgrade movements by preventing surface water intrusion. However, its role is dependent on its material properties and tack coat application.

In terms of moisture related distresses in pavement structures, frost heave and capillary rise are highlighted as two main issues. The former can cause differential movements in subgrade and base course layers, while the latter can make changes in stiffness of pavement soils. Therefore non-woven geotextiles may be used as a barrier to capillary flow. In a study, two types of soil-geosynthetic systems (isolated geotextile and geocomposites, comprising drainage net) as well as the control specimens were subjected to freezing temperature. The results showed that air gap within the drainage net was effective in preventing upward movement of water into the overlying soil layer, and reducing frost heave. A study on use of geotextiles to reduce water fluctuation by capillary rise from lower layers in base courses revealed that embedding geotextiles a few centimeters above the water table, and above the level at which the water content approaches saturation (Zornberg et al., 2010).

An extensive study on the effectiveness of geocomposite membrane at the Virginia Smart Road was conducted. By using time domain reflectometry and ground penetrating radar, it was observed that the geocomposite suppresses penetration of water into the subbase layer leading to prevention of saturation of underlying layers and water to be drained to the pavement shoulder (Elseifi et al., 2001).

For the drainage purposes of using geosynthetics in pavement structures, a special geocomposite drainage net with a higher flow capacity was examined in three different levels of pavement structures. That is, base course aggregates, in asphaltic materials, and subgrade. The results indicated that placing it at the subgrade or below it had the best effect on removing rapidly the damaging waters (Christopher et al., 2000).

Furthermore, geocomposite capillary barrier drain (GCBD) can drain the soil while the pore pressures remain negative. In pavement structures, this system is usually placed between subgrade and base layers. A GCBD with a fiber glass transport layers was laid down between subgrade and base layer, was evaluated in three phases, namely, constant rate infiltration, subsequent drainage with no infiltration, and transient infiltration corresponding to a design storm. The results indicate that the system is effective in preventing positive pore water pressure to be developed in the base layer, and water penetration into the subgrade (Stormont et al., 2001).

Cushion (strain-relieving or stress absorbing)

The other purpose of using the geosynthetic materials is for absorbing stress being applied to pavement structure. A stress-relieving layer for an overlay acts as a means to retard and control some common types of cracking, including reflective cracking (Hosseini et al., 2009). However, it should be noted that strain relieving function of geotextiles, that only hinder reflective cracks, may occur only if elastic stiffness of geotextile is lower than the surrounding AC (Lytton, 1989). In 1988, a system was developed based on conventional geotextiles consisting of a spunbonded non-woven fabric and a polymer modified hot bitumen. It was a visco-elastic textile/bitumen interface system. Using them in pavement structure appeared to be effective in preventing reflective cracks although like other treatments, it cannot be considered as a universal cure for such cracking phenomena (Perfetti, 1988). In addition, the amount of tack coat used to attach the geotextile to the layer below it plays an important role. The tack coat must always be somewhat above the optimum level as defined by the method for determining it, but not so great as to cause a significant loss of shear strength on the horizontal plane below the geotextile (Lytton, 1989).

One of the well-known types of geotextiles is paving fabrics. In order for geotextiles to form a membrane interlayer system, they are usually combined with asphalt sealant, or tack coat. This system is also known as a paving fabric interlayer (Hosseini et al., 2009). In a study carried out on four kinds of paving fabrics in the purpose of identifying whether they are able to retard reflective cracking, the surveys and data collection were conducted eight months, 26 months, and 44 months after construction. In spite of varying amount and rates of reduction, all treatments retarded cracks over the evaluation period (Maurer and Malasheskie, 1989). However, in other research on fabric interlayers it was deduced that they may act most effectively when used for load-related fatigue distress and are not functioned well in case of being used to delay or retard thermal cracking (Amini, 2005).

The other type of treatments by geosynthetic is using interlayer stress absorbing composite (ISAC). The performance of a kind consisting of a very high-stiffness geotextile at the upper layer, a viscoelastic membrane layer as the core, and a low-stiffness geotextile for the bottom layer was observed in laboratory and on the field (Highway and airport). The ISAC system was found to be significantly effective in lessening reflective cracking (Dempsey, 2002). Moreover, a specially designed geocomposite membrane was examined to determine its ability to retard the reflective cracks in flexible pavements, and its effectiveness was evaluated through a two dimensional finite element modelling. It was observed that as long as the interlayer is intact, and having proper thickness and properties, meaning that crack is not to pass through it, the crack tip strain energy would be dissipated. In addition, a membrane acts as a protective shield around crack tip. Meanwhile, the crack may be closed by a resultant compressive horizontal stress field (Elseifi and Al-Qadi, 2005). Stress absorbing membrane interlayer (SAMI) is another system being used in pavements to retard reflective cracks. In a study a fiber-reinforced asphalt treatment used as a stress absorbing membrane interlayer (SAMI) to mitigate reflective cracking. In spite of the fact that only partial improvement was observed in improving reflective crack resistance due to the incorporation of the interlayer, it may also considered as a countermeasure to improve the reflective crack resistance of AC (Palacios, 2008). Thus, strain absorbing function of geosynthetics in pavement, despite wide range of effectiveness and various-factor dependency, appears to be positively productive.

Reinforcement

Reinforcement is the other function of geosynthetic material in pavements. Such material structurally strengthens the pavement section by changing the response of the pavement to loading, causing to have a chance to re-direct the reflective crack. In general, ribs of the geogrid, which suppress the growth of a crack (Saraf and Majidzadeh, 1974), and deforming of geogrid, that absorbs the energy at the tip of the crack (Saraf et al.,

1996) are the main causes in stopping growth of the crack. Many researches have been performed for the purpose of achieving an insight to reinforcement characteristic of geogrid. In 1982, one of the earliest studies used stiff biaxial geogrids for reinforcing of asphalt at Canvey Island, near London, England, where 10,000 m^2 of geogrid were used to control reflective cracking over a cracked concrete pavement (Austin and Gilchrist, 1996). The mechanism of reinforcement can only occur if the geosynthetic properly constructed, has a higher modulus compared to AC and sufficient cross-sectional area to substantially strengthen the overlay (Khodaii et al., 2009; Lytton, 1989). Similarly, it was concluded that in order to ensure a satisfactory performance of pavement, the bonding between geosynthetic reinforcement and asphalt and the stiffness of geogrid are of great importance (Kikuata and Muramatsu, 1998; Ling and Liu, 1999).

For reinforcement purposes geosynthetics can be placed both in aggregate layers of pavement, and in asphaltic layers of it. The main reinforcement mechanism in paved roads is usually called base or sub-base course restraint, and subgrade lateral restraint (Berg et al., 2000). In a full-scale accelerated test in which geo-syntehtic materials were embedded in aggregate layers showed that geogrid can significantly reduce horizontal shear deformation of the aggregate layer, particularly in the traffic direction. Furthermore, pavement structure composition and layer thickness were identified as decisive factors to pavement performance and the distress type developed (Al-Qadi et al., 2008).

The results of another full-scale field test which was carried out on a strain-gauge instrumented geogrid reinforced unpaved road in Switzerland indicated that using various geosynthetics have a relevant reinforcing effect only when a thin aggregate layer is used on a soft subgrade. The stiffness of geosynthetic affects the degree of reinforcement which can be accomplished and is limited by finite lateral anchoring forces (Hufenus et al., 2006).

The performance of pavement structure depends not only on how aggregate layers perform, but the role of asphaltic layers is also important. Extensive studies have been performed on behaviour of geosynthetics in AC. Results of a research on geogrid reinforced samples indicated a significant reduction in the rate of crack propagation in reinforced samples. In addition, type of old pavement (concrete or asphalt pavement), geogrid position and temperature were found as factors affecting the type of crack propagation in asphalt overlays (Khodaii et al., 2009).

In terms of effectiveness of geogrids in improving the resistance of AC to fatigue failure, the results of one of the earliest studies on reinforcement effect of a kind of high tensile strength plastic geogrid known as Tensar, revealed that by using Tensar, fatigue crack resistance may be developed, thickness savings of asphaltic materials may be achieved, and number of load repetition may be doubled (Halim et al., 1983).

In addition, a laboratory and case study performed in Taiwan where three types of geogrids, two of which made by glass fiber and the other by high density polyethylene (HDPE) were tested. Based on fatigue test of AC beams placed on clearance rubber, fatigue lives of glass grids of 100 kN/m strength and HDPE geogrids were 3 to 5 times greater than those of an unreinforced beam; this value for glass grids of 200 kN/m strength was 5 to 9 times. Besides, obtaining 10 month rutting depth measurements from the site, confirmed the improvement from the geogrids (Chang et al., 1999). This may imply that geosynthetic reinforcement can be used for fatigue related problems of pavements as well. Due to complex behavior of bituminous materials such as plastic flow, examining such characteristics can be functional and help to have pavements with long performance lives. The effectiveness of high-modulus and high-strength polyoxymethylene fiber geogrid on plastic and crack resistance of AC was examined in Japan through wheel tracking machine. The results indicated a remarkable increase in viscosity and durability of reinforced AC. Moreover, in this study durability was correlated to geogrid mesh size and degree of adhesion of it to AC, meaning that by decreasing size of the mesh and increasing adhesion, the durability improves (Kikuata and Muramatsu, 1998).

A research was carried out in National University of Singapore to set a logical basis so as to design and analyze the porous asphalt pavement for car parks and roads in Singapore. By means of large scale laboratory wheel tracking tests, using geogrid in the surface course interface, geogrid was found effective in providing rutting resistance under local condition (Ong and Fwa, 2005), implying that geogrid may be utilized not only in hot mix asphalt which is common place, but also in other types of AC.

Depending on the means pavement structure is used, it may tolerate different types of loading. In this regard, a research on geogrid reinforced AC through monotonic and cyclic static loading as well as dynamic loading under plain strain conditions was conducted. It was found that stiffness and bearing capacity of the AC pavement were increased by inclusion of geogrid. This improvement was more significant for dynamic loading compared with static loading (Ling and Liu, 1999). Consequently, it might be said that the amount of success can be achieved in sections of pavement experiencing mostly static loading e.g. parking lots might be less than parts enduring dynamic loading such as on high speed highways.

In a study by Mahrez and Karim (2010), found that the improvement in fatigue life due to reinforcement is more considerable at higher stress level as compared to low stress level. Hence the enhancement of reinforced bituminous mix as fatigue barrier is more significant and useful when heavy trafficked road is concerned rather than normal trafficked road. This is good and practically acceptable since the normal trafficked road are less prone to fatigue, thus the reinforcement in this case will provide some improvements but in the same time it will increase the cost, however at heavy trafficked roads which are more prone to fatigue failure the reinforcement of asphalt concrete will provide great improvements in fatigue life, therefore the reinforcement here might be more cost effective by reducing the maintenance cost in the same time prolongs the working life of the road structure.

Mathematical modeling is one of the methods used to estimate the behavior of materials without performing many expensive tests and spending a lot of time. In Italy a research developed a precise model which simulates the mechanical behaviour of bituminous mixtures and allows a reliable comparison amongst the different bituminous systems tested. It was performed by means of 4PB test under repeated loading cycles on bi-layer bituminous systems reinforced with three different geosynthetic materials. No fracture was observed in geosynthetic-furnished samples, and it was concluded that the 4PB test can discriminate the differences between treated and untreated specimens (Virgili et al., 2009).

Nowadays, the use of geogrids made by glass in pavement structure is also propounded. Based on an extensive study carried out on glass grid reinforced laboratory pavement sections, and comparing the results with 3D finite element computer modeling output, it was concluded that by including the glass fiber grid, performance of pavement is raised. It was also deduced that glass grid provides a crack propagation resistance for AC (Siriwardane et al., 2010). Moreover, a mathematical modeling was carried out by employing theory of fracture mechanics, and the crack growth resistant ability of glass grid reinforced asphalt overlay was determined. Asphalt mix design tests, three point bending tests, and fatigue crack propagation tests were carried out. The results showed that glass grid improves crack resistance ability of AC through its low rate of elongation and its high tensile strength, and it is able to offer a suitable solution for reflective cracks (Zheng and Aysar, 2007). In another study in South Korea, four types of modifying and three kinds of reinforcing materials were examined. Different combination of them was effective in improving AC performance. However, the most remarkable effect took place when modified asphalt was reinforced with a glass fiber grid, leading to an increase in fatigue life and dynamic stability by up to 20-30 folds (Kim et al., 1999).

Geonets, also known as geospacers, are another type of geosynthetic materials. Generally, the nets used to enhance the pavement performance are embedded between the base layer and the sub-base layer. However, recently, the use of steel reinforcement net between the binder layer and the base layer was examined. It was observed that steel reinforcement develops fracture resistance of asphalt pavement at all temperatures, and a 3D-FEM simulation was developed for the experiment, both of which were in accordance with each other (Montepara et al., 2007). Moreover, the ability of steel reinforcement netting interlayer system to retard reflective cracks was simulated utilizing three-dimensional finite element method and the ABAQUS cohesive zone model. The results of analysis showed that by means of steel reinforcement netting placed between the HMA overlay and existing PCC, reflective crack initiation time increased by seven times (Al-Qadi and Baek, 2008).

Geocomposite, a function of which is reinforcing the pavement structure, consists of geotextile, geogrids, geonets and/or geomembranes, is another type of geosynthetic material. Based on a research, a composite combination of stiff polypropylene geogrid with a geotextile which is resistant to normal asphalt paving temperatures can improve the surface deformation resistance of pavements as well as providing ease in installation of geogrids. Moreover, pavements furnished with this geocomposite are able to resist large horizontal strains that develop in the bituminous material at the level of the geogrid. In addition, reinforcing composites in the bound layers of the pavement may have an important role in reducing the stresses of subgrade in a pavement on soft foundations (Austin and Gilchrist, 1996). Another research on this matter which was carried out on large dimension asphalt samples in Poland, showed that by applying repeated loading test, the samples reinforced with geocomposites functioned better compared with geogrid reinforced samples on fatigue crack resistance behavior (Grabowski and Pozarycki, 2008). Similarly in comparison with paving fabrics, a study was performed on geocomposite reinforced, paving fabric reinforced, and unreinforced asphalt beams by three different levels of loading for each set. It was observed that geocomposite included set had the best performance and paving fabric inclusion functioned better in comparison with unreinforced set (Saraf et al., 1996).

In summary it can be said that reinforcement of pavement by geosynthetics may increase the resistance of pavement structure against distresses. However, care must be taken that various geosynthetic materials may have different reinforcement levels, meanwhile, the reinforcing ability of a certain geosynthetic may be influenced by several factors.

CONCLUSION

This paper presented the benefits of applying geosynthetics in pavement structures. Therefore, it was revealed that geosynthetic materials are commonly utilized in pavements for three dissimilar purposes, namely, waterproofing, strain absorbing, and reinforcement. Waterproofing function is affected highly by tack coat and bitumen impregnation of geosynthetic materials. Furthermore, it may also be inferred that the main difference between strain reinforcing and reinforcing action of geosynthetic is in its elastic stiffness, meaning that as a strain absorbing agent, the stiffness of the geosynthetic is less than its surrounding materials, whereas in reinforcing role, its stiffness is higher than stiffness of adjacent materials. Generally, geosynthetics when used in AC layer can change the stiffness, durability, reflective cracking, fatigue, and rutting resistance of AC, as well as surface deformation, and applied stress on subgrade. Moreover, it was indicated that in reinforcing behaviour, stiffness of geosynthetics, cross-sectional area, pavement structure composition, and layer thickness are decisive factors.

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