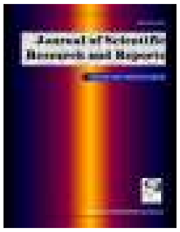

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A Review on the Use of Stress Absorbing Membrane Inter Layers (SAMIs) as Remedy for Reflective Cracks in Pavement

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Authors' contributions

The authors considered the topic–reflective cracking and the Nigeria's situation in some of their research meetings and advanced a position on the use of SAMIs to combat the problem of reflective cracking on overlays in Nigeria.

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ABSTRACT

This paper looks at the need for Nigeria to adopt innovative road maintenance strategy to reduce the colossal amount expended on construction and maintenance of roads. Federal government budget to Federal Ministry of Works in 2012 is ₦199, 032, 816, 621 (199 billion). Federal roads account for only 17% of total roads in Nigeria with Local government roads being 67% of the total. It highlights the defects in road pavement in general with emphasis on reflective cracking, which is the major problem of overlaid pavement, its causes and mechanism. The paper reviews successes recorded in the use of Stress Absorbing Membrane Interlayers (SAMIs) which is the use of stress-relieving interlayer at the interface between the overlay and the old pavement. Its use for both road

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and airport pavements has been largely successful based on the series of laboratory and field examinations.

Keywords: Reflective cracking; overlay; SAMIs; pavement; maintenance.

1. INTRODUCTION

Good roads are important to the socio-economic development of any nation. In Nigeria it is the major mode of transportation. It is therefore a necessity that our roads are in good condition and safe to travel on. Nigeria roads are classified into three vis-a-vis Trunks A, B, and C. Trunk A roads link various cities, regions, and capitals in the country and are controlled by the Federal government. The agency of government charged with the responsibility of construction of the roads is the Federal Ministry of Works, while another body of government that performs the sole function of routine maintenance of the Trunk A roads is the Federal Road Maintenance Agency. Trunk B roads link various cities in the country and are controlled by the State Ministry of Works. Also, the state governments have their own maintenance agencies charged with the responsibility of routine maintenance though mostly ineffective. Trunk C roads are rural and street roads that provide access to the residential and recreational areas and allow the citizens to assess basic amenities necessary for the sustenance of life. They are controlled by the local arm of government. Table 1 shows the road network of Nigeria [1].

However, it is sad to note that despite the huge sum of money the government claimed to have spent on our roads, they are still in bad state endangering lives and hindering the country's economic growth. Table 2 shows the summary of Federal Government of Nigeria (FGN) 2012 budget for the Federal Ministry of Works [2].

Table 1. Road network of Nigeria [1]

Type of road	Federal road	State road	Local govt. road	Total
Paved roads	26500	10400	-	36900
Unpaved roads	5600	20100	-	25700
Urban roads	-	-	21900	21900
Main rural roads	-	-	72800	72800
Village access roads	-	-	35900	35900
Total	32100	30500	130600	193200
Percent	17%	16%	67%	100%

Traffic clashes impact on the economy of developing countries at an estimated cost of 1-2% of a country's Gross National Product (GNP) per annum as a result of morbidity, mortality and property related cost [3]. According to Odero et al. [4], a high prevalence of old vehicles that often carry more people than they are designed for, lack of safety belt and helmet use, poor road design and maintenance and traffic mix on the roads are some of the factors that contribute to the high rate of crashes in less developed countries. The periodic Road Traffic Accident (RTA) rates for Nigeria are shown in Table 3 [5].

Table 2. Summary of FGN 2012 budget for federal ministry of works [2]

MDA	Total personnel cost (₦)	Total overhead cost (₦)	Total recurrent (₦)	Total capital (₦)	Total allocation (₦)
Main ministry	3,748,648,063	609,525,640	4,358,173,704	143,592,745,849	147,950,919,552
Office of the surveyor general of the federation	766,800,097	116,204,949	883,005,046	4,400,781,295	5,283,786,342
Federal school of survey, Oyo	598,291,065	62,847,251	661,138,315	312,396,000	973,534,315
Federal road maintenance agency	1,585,614,547	31,740,000,000	33,325,614,547	10,512,810,000	43,838,424,547
Council for the regulation of engineering in Nigeria	155,127,469	19,899,309	175,026,778	194,436,000	369,462,778
Surveyor council of Nigeria	135,880,922	30,447,607	166,328,529	307,640,000	473,968,529
Regional centre for training in aerospace survey	-	-	-	142,720,558	142,720,558
Total	6,990,362,164	32,578,924,756	39,569,286,920	159,463,529,702	199,032,816,621

Table 3. Periodic road traffic accident rates for Nigeria [5]

Period	Severity rate per 100 RTA	
	Killed	**Injured**
1960-1969	13	70
1970-1979	22	72
1980-1989	32	89
1990-1999	41	111
2000-2004	48	144

Rehabilitation of pavements is one of the major activities that the engage time and resources of many highway agencies around the world. This is because when road pavements (flexible, rigid and composite) deteriorate, the needs arise for them to be restored back to good condition. Rehabilitation of road pavements is essential, as bad roads have accounted for many accidents and loss of lives. Overlaying the old pavement with new surfacing material is one of the commonly used methods for rehabilitating deteriorated pavements. Cleveland et al. [6] stated that for both flexible and composite pavements, a common technique used by many agencies for preventive maintenance and/or rehabilitation was simply to construct a thin Hot Mix Asphalt (HMA) overlay, normally between 1 and 2 inches (25 and 50 mm) thick. The approach was designed to protect the existing surface against water intrusion, reduce roughness, restore skid resistance, increase structural capacity, and improve the overall ride quality to the travelling public [6].

Repairing cracked roads by overlaying has been found to be a short term solution. This is the case because the deficiencies in the old road are rapidly reflected at the surface as a result of the combined effects of thermally induced stresses and traffic loading [7]. This phenomenon referred to as reflective cracking is one of the more serious problems associated with the use of thin overlays. It has long been a problem in pavement rehabilitation [8] and has emerged out as a major challenge to pavement designers in the last four decades [9]. Reflective cracking is first initiated at the bottom of the overlay material and grows until it appears at the surface. Once a reflective crack reaches the surface, it creates a path for the flow of surface water into the lower layers of the pavement. When left untreated, this situation will lead to deterioration of the pavement structure and a reduction in serviceability [10]. Breakdown of the pavement is particularly rapid in areas where the annual precipitation is higher, or where the applied loads are greater in magnitude. Pavements associated with aircraft loads (runways, aprons, taxiways, etc.) are therefore of particular concern [10]. The breakdown of the pavements usually results in discomfort to road users and increased maintenance cost, because in most cases the road will have to be rebuilt from the foundation (subgrade). The prevention of reflective cracks will help to extend the life of an overlay and generally reduce highway maintenance costs, hence the need to intensify efforts to provide acceptable solution to the problem.

1.1 Road Pavement Defects

The reason for rehabilitating road pavements by overlaying with a surfacing material is because of the defects which occur in the old pavement, hence the need to look at the forms of defects in pavements. Defects may occur in pavements during construction and while in service. This may be due to the material used for pavements construction, poor workmanship, environmental factors and the loading to which they are subjected. Some of the defects in flexible and rigid pavements are highlighted in Table 4.

Table 4. Defects in flexible and rigid pavements

Type of pavement	Defects
Flexible	Fatigue, longitudinal, reflective, block and transverse cracking, corrugation or shoving, depression/potholes, rutting, polished aggregate, ravelling, etc.
Rigid	Longitudinal, transverse, and map cracking, lane-to-shoulder dropoff, lane-to-shoulder separation, spalling/faulting, punchouts, corner breaks, popouts, blowups, polished aggregates etc.

This paper therefore reviews innovative way of combating the problem of reflective cracking associated with overlaying of pavement.

2. REFLECTIVE CRACKING

Debondt [11] defined reflective cracking as the propagation of cracks or joints from old pavement into and through the overlay. Caltabiano [12] described it as the propagation of a previously defined crack through subsequent layers of a pavement. Shalaby and Frenchette [13] defined it as the premature occurrence of cracks on overlays at positions and orientations that corresponds to locations of cracks in lower pavement layers.

Summarily, reflective cracking can be defined simply as the propagation of existing cracks on old pavement through the underside of the overlay to the surface. All these definitions imply that two processes are involved in the appearance of reflective cracks on the surface of the overlays, which are the crack initiation and crack propagation processes. The problem of reflective cracking in overlaid pavement led engineers to looking for innovative maintenance strategies in order to avoid premature failure of the overlay. To address the problem of reflective cracking successfully, the causes and mechanism of reflective cracking must be known.

2.1 Causes and Mechanism of Reflective Cracking

Based on the causes identified by researchers, the principal factors responsible for reflective cracking are the action of traffic loading on overlay on cracked pavement and thermal stresses developed on the crack tip as a result of daily/seasonal temperature variation [14-17]. Debondt [18] stated that cracks did not necessarily grow with a constant rate throughout the entire cross-section of the overlay (the variation of the rate mainly depends on the type of loading). When a load passes over a crack in the old pavement, three pulses of high stresses concentration occur at the tip of the crack as it propagates upwards through the overlay. The first is the maximum shear stress pulse. The second stress pulse is the maximum bending stress pulse and the third is again a maximum shear stress pulse but in opposite direction of the first one. The mechanism of reflective cracking clearly indicates that there are three modes of reflective cracking. Molenaar [19] established the three modes: mode I cracking occurs due to the tensile stresses caused by a drop in temperature, mode II cracking is caused by the effects of shear stress induced by a loaded wheel crossing from one side of a transverse crack or joint to the other. This also produces flexure contributing to mode I cracking and the third mode (mode III) referred to as the tearing mode has not been given much attention. The tearing mode (mode III) occurs in pavement when the wheel travels parallel to an existing crack in a pavement. Fig. 1 depicts the three modes of cracking.

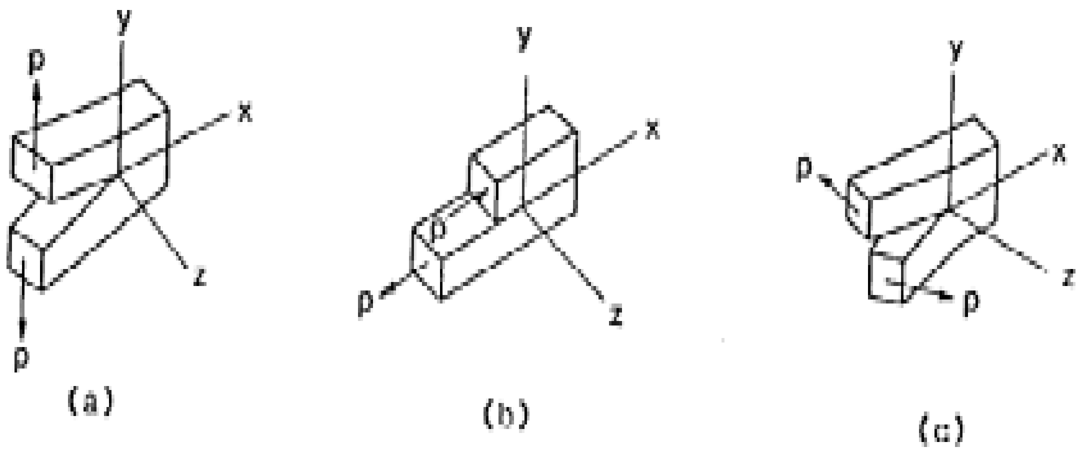

Fig. 1. Modes of cracking (a) mode I (b) mode II and (c) mode III

3. INNOVATIVE MAINTENANCE STRATEGY

This involves the use of interlayer materials between the existing pavement and the overlay. These materials are required to have lower stiffness than both the overlay and the existing pavement. Therefore, they are referred to as Stress Absorbing Membrane Interlayers (SAMIs). They are termed SAMIs because they relieve stress and reduce strain concentration in the crack region, therefore prolonging the life of the overlay.

3.1 Stress Absorbing Membrane Interlayers (SAMIs)

These are interlayers designed to dissipate energy by deforming horizontally or vertically, therefore allowing the movement (vertical/horizontal) of the underlying pavement layers without causing large tensile stresses in the asphalt overlay. Barksdale [20] defined a stress-relieving interlayer as a soft layer that is usually thin and is placed at or near the bottom of the overlay. He stated further that the purpose of the soft layer is to reduce the tensile stress in the overlay in the vicinity of the crack in the underlying old layer and hence “absorb” stress. The application of stress-relieving systems at the interface between the overlay and the old pavement surface reduces the shear stiffness of the interface. Debondt [11] proved using theoretical analysis that the reduction of shear stiffness allows slip of the interface, thereby isolating the overlay from the stress concentration of the crack tip.

Lytton [21] summarised stress relief failure mode as follows:

The crack starts to propagate (due to thermal and traffic loading) from its original position upwards until it reaches the stress-relieving layer. Due to its low stiffness, the interlayer will exhibit large deformations, which will be accompanied with a dissipation of energy. The crack propagation will stop for a while due to the lack of energy, and then propagate from the top of the interlayer upward to the surface (bottom-up cracking). In the second failure mode, the crack starts to propagate from its original position upward until it reaches the stress-relieving layer. The crack then begins from the top of the overlay to the interlayer (top-down cracking).

The different types of SAMIs include geotextile, modified binder, sand asphalt, impregnated glass fibre, Interlayer stress absorbing geocomposite (ISAC), bitumen-impregnated glass fibre, etc. They are usually placed or laid between the existing pavement and the overlay. The process requires that the existing pavement be cleaned, to ensure they are free of dust and other deleterious substances.

4. SUCCESS STORIES

The cases in which the innovative maintenance strategy - use of stress absorbing membrane interlayers have been examined in the laboratory and found capable of delaying reflective cracking are reported. Also, instances in which they have been used successfully in the field or in accelerated pavement testing facility are mentioned.

4.1 Laboratory Examination of SAMIs

Many researchers around the world had investigated the crack resistance potential of the innovative maintenance strategy and found it capable of retarding reflective cracking. Some of them are highlighted below:

Caltabiano [12] carried out a series of beam tests to assess the performance of interlayers to delay the propagation of cracks through asphaltic concrete overlays. The SAMIs examined are polymer modified binder and geotextile interlayer. In order to further ascertain the performance of the interlayers, he also conducted tests on slabs with and without the interlayers. He reported that although there was debonding between overlay and timber bases (old pavement), the polymer modified binder and geotextiles interlayers gave 2.5 and 5.0 and 10 increase in life, respectively. Nataraj and Vander Meer [22] studied the use of a Crack Relief Layer (CRL) in airport pavements for rehabilitation of existing pavements and for construction of new ones using triaxial tests. They observed that CRL specimens showed a large initial permanent vertical strain. After the initial phase the further development of permanent deformation in the CRL specimen was limited. They concluded that the CRL would perform well under heavy aircraft load without traffic densification or rutting and would play a significant part as a structural layer in the total pavement. Blankenship et al. [23] reported the use of an interlayer of asphalt rich, highly polymer modified binder and fine aggregate hot mix to retard reflective cracking. Their results showed that specimens with reflective crack relief interlayers had a minimum of 100,000 cycles at 2000 micro strain before failure, while unmodified asphalt typically failed at 2000 cycles. A high quality polymer modified asphalt such as PG76-28 withstood three times as many cycles as the unmodified asphalt, but still failed at 6000 cycles at 2000 micro strain. Prieto et al. [24] carried out research at the Road Laboratory of the Technical University Madrid in Spain to gather insight into the reflective cracking phenomenon, the evolution and configuration of the cracks and bonding conditions between materials. The potential benefit of using three different geotextile inclusions was studied. The results indicated that the crack reflection strength values for specimens with geotextile were greater than those without. Bhosale and Mandal [9] carried out a laboratory study on Open Graded Asphalt Concrete (OGAC) as a crack relief layer using an asphalt concrete slab fatigue testing equipment. They concluded that the conventional overlay of DBM showed a faster rate of decay with the number of simulated thermal load cycles than the OGAC overlay.

Moses [25] evaluated SAMIs comprising chopped glass fibre, bitumen emulsion and 6mm single sized aggregates and found that they were able to delay appearance of cracks in an overlay over a cracked pavement. He stated that the factors that affect the performance of the SAMIs include the magnitude of the wheel load, overlay thickness and temperature. Also, Ogundipe [26] observed in his finite element analysis of typical SAMIs that greater deflections usually occur when SAMIs are introduced in cracked pavement. He stated this was due to the low stiffness of the SAMIs, which contributes to the increased crack resistance of the overlaid pavement.

Ogundipe et al. [27] evaluated the performance of SAMI under traffic loading using accelerated pavement test facility. Their study showed that the SAMI was able to retard reflective cracking. They found that the slip at the interface of the pavement and SAMI interface isolated the pavement from the relative vertical movement of the underlying layer and strain concentration around the crack region.

It can be seen from the few cases reported that the examination of the innovative maintenance strategy in the laboratory has shown that using interlayers and in particular SAMIs between existing pavement and overlay will increase the life of the latter.

4.2 Field Examination of SAMIs

Researchers had examined the performance of the maintenance strategy in the field and using accelerated pavement testing facilities. Some are highlighted below:

Engle [28] investigated the effectiveness of two engineering fabrics: PavePrep and Proguard, to reduce reflective cracking on County F16, Audubon County, Iowa US. The data indicated a statistically significant decrease in reflective crack formulation in the Proguard fabric sections compared to the control. There was little evidence of a similar effect for the PavePrep fabric section compared to the control.

Also, Elseifi [29] evaluated the potential of a specially designed geocomposite membrane to delay the reflection of cracks in flexible pavement systems using a 2D finite element model and Falling Weight Deflectometer (FWD). The geocomposite membrane was made of a 2mm thick low modulus Polyvinyl Chloride (PVC) backed on both sides with polyester nonwoven geotextile. The test demonstrated the importance of having an overlay mixture with good properties and that caution should be taken in the design of the overlay mixture and thickness. Furthermore, Antunes et al. [30] carried out eight years' performance monitoring of anti-reflective cracking solutions. The anti-reflective solutions considered in the study were SAMI with modified binder, cold asphalt concrete overlay, bitumen-impregnated geotextile and steel mesh with slurry. Also, two sections were constructed of asphalt concrete without anti-reflective cracking solution (reference). They monitored the performance of the test sections between 1998 and 2005 and found that the section where cracking and rutting were developing fastest was the one with the cold asphalt overlay, and the sections with better performance were the ones with bitumen-impregnated geotextile and steel mesh reinforcements. Lastly, Palacios et al. [14] evaluated the use of fibre reinforced asphalt treatment as a Stress Absorbing Membrane Interlayer (SAMI) to mitigate reflective cracking. Their study involved field evaluation and comparison of overlays with interlayers and those without an interlayer (control) on pavement test sections at the Pennsylvania Transportation Institute (PTI) test track. They concluded the use of fibre-reinforced interlayer gave partial improvement in reflective cracking resistance. The examination of the field cores showed no reflected cracks were observed in the cores from the SAMI section, however an existing crack was observed propagating towards the surface of the new layer in the control section.

The results from the studies conducted with few highlighted above have shown that the maintenance strategy has been successful when used in the field.

5. NIGERIA SITUATION AND THE WAY FORWARD

Recent study ranked our roads 191st position out of 192 countries whose roads were rated based on safety standards [31]. This shows our roads are the second worst in the world, a situation that is reflected in the dwindling economy of the nation. This is because availability of good transportation system is very vital to the industrial growth of any nation and subsequently her economy growth. This informs why some companies have relocated from Nigeria to other countries where transportation and other essential infrastructure for economy growth are in good state. This has led to increase in unemployment and spread of poverty in the nation.

Having seen the successes recorded with the use of SAMIs. It is imperative on our governments, highway agencies at Federal, State and Local levels to start adopting a better way of maintaining our roads. Knowing that, the success stories reported were not in the tropical countries, which have different environmental conditions to the temperate region. It is important that more studies are conducted in the tropics. The onus is on our governments through the highway agencies, road contractors and other private establishments to fund research in this area. Some of the benefits that could be derived from the use the innovative strategy include: (i) Increase in the lifespan of the overlay; (ii) Availability of smooth, safe and comfortable roads for users; (iii) Reduction of users' cost; (iv) Protection of the foundation from deterioration by preventing infiltration of water into lower layers of the pavement and; (v) Reduction of road maintenance cost.

6. CONCLUSION

This write-up has established the need for agencies of government charged with the responsibility of maintaining our roads to start adopting the innovative maintenance strategy for rehabilitation work involving overlaying of existing pavement. This will go a long way in addressing the dwindling industrial growth and subsequently the economic growth of the nation. It looks at the main problem with overlaid pavement, that is, reflective cracking, its causes, which are the action of traffic and thermal loadings and the mechanism, which shows there can be mode I, II and III. The successes that had been recorded in the field and laboratory examinations of the innovative maintenance strategy show that the method could be adopted and more investigations would be necessary for tropical conditions.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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