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RETARDING REFLECTIVE CRACKING IN ASPHALT PAVEMENTS BY USE OF A WOVEN POLYPROPYLENE FABRIC INTERLAYER

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Abstract

Retarding reflective cracking in bituminous pavements is a problem that faces the majority of Design Engineers involved in carriageway maintenance. The use of geotextiles and related products in this end has become markedly more widespread in the United Kingdom in recent years. These products can extend the pavement lifetime to a degree that makes their inclusion justifiable or desirable. A wide range of materials has become available to offer either reinforcement or stress relief, but until recently, there were no products that have sought to solve this problem by both means together. The development of combined materials such as reinforced non-woven geotextiles, composite geogrid / non-woven geotextile materials and woven polypropylene fabric interlayers has offered the Engineer a third choice, albeit at very widely differing costs. High strength woven polypropylene fabrics have been used with great success as a part of systems to retard the reflective cracking of asphalt pavements. This paper reviews their use and the comparative performance and cost of these and other geotextile interlayers, currently widely used in the United Kingdom.

Keywords: Bituminous surfacing, geogrids, geotextiles, pavement lifetime, reinforcement, stress relief.

1 Introduction

The trend to use geotextile interlayers in the retarding of reflective cracking has, until recently centred mainly on the use of two types of material, stress relief fabrics and reinforcement grids. Their ability to bring about the requisite increase in lifetime which will justify their installed cost in the scheme varies. If the material will not give a lifetime extension that the Engineer can be sure will be economically viable then it is certainly, at the very least, a great act of faith by that Engineer to specify its inclusion. Reviewing current practice, how each of the types of product act to retard the onset of reflective cracking, their relative advantages and disadvantages and their relative installed cost will help the Engineer to determine which materials are viable for his scheme.

2 Current practice

There are several reasons why reflective cracking occurs and an understanding of which circumstances have contributed to the pavement damage previously may be used to decide the most appropriate action thereafter. These reasons summarised by Walsh [1] include;

1. Thermal stresses, induced in stiff bituminous bases and in cement bound macadam bases. These may be exacerbated by premature trafficking of the pavement in the case of the former or later during the

pavement's life. In the case of the latter, internal thermal effects during the initial curing are noted as being a significant contributor to the later cracking of the pavement.
2. Traffic stresses, usually not the root cause of cracking in themselves albeit that the loading by traffic will undoubtedly accelerate reflective cracking.
3. Changes in construction, usually in areas where the carriageway has been widened or where service openings have been made and reinstated.
4. Settlement, in areas where the foundation has expanded, contracted or moved inducing movement in the pavement above.

Historically the Engineer had two choices how best to alleviate reflective cracking. If levels allowed then a thick overlay (or to a lesser effect, a thinner but stiff overlay) may lessen the speed with which the cracking reaches the surface and also reduce the amount of thermal or traffic stress that reaches the base of the pavement. In all other circumstances the Engineer would be driven to consider a reconstruction of the carriageway, removing the cause of the failure in the process. Two further options became available with the introduction of polymer modifying additives to the bitumen binder and the advent of geotextile interlayers. The former have been widely trialed and have unfortunately yielded results that suggest that they are not as effective as had been hoped. The latter, being the subject of this paper, have gained favour with many Engineers and continue to attract interest as the only viable alternative to the three options described above in the combating of reflective cracking damage.

The specifier currently chooses an interlayer to alleviate reflective cracking on the basis of its' ability to;

1. Reinforce by offering tensile strength to the asphalt
2. Relieve stress by transferring movement stresses into a bitumen impregnated fabric

As would be expected, there are a large number of products available to the Engineer to offer these effects. These can be divided into groupings as above. All must act by meeting the cracks that emanate through the structure of the pavement but their action in combating these cracks is subtly different. (Fig. 1)

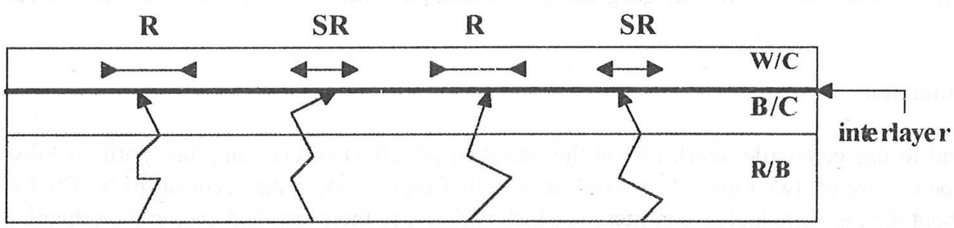

Fig. 1 Reflective cracking being controlled beneath the wearing course by reinforcing (R) and /or stress relief (SR)

2.1 Reinforcement

Asphalt has a low tensile strength. Kirschner [2] observed that this tensile strength can be exceeded by the result of strains as little as 2-3%. When this tensile strength is exceeded, cracks will form in the asphalt course, leading to its premature failure. The inclusion of a material such as a geotextile or geogrid with a high tensile strength and, often, low elongation (measured by a test method such as B.S. 6906 [3]), the crack (or potential cracking zone) is bridged by the material.

Kirschner identified the requirements of the optimum asphalt reinforcement. He determined that the tensile strength of the reinforcement should be not less than 35kN/m in both material directions and that it should have a maximum elongation at break of 15%. More specifically he concluded that the material should, at a strain of 3%, exhibit a tensile strength of at least 10kN/m in order to absorb stress even when there is little strain induced in the pavement.

These products act to stitch each side of the crack together and stop any lateral movement of the lower pavement layers. These materials are reliant upon the fact that they must have a modulus of elasticity that, by being greater than the material into which they are laid, allows them to offer that material reinforcement. To achieve this there must be an efficient bond between the reinforcing elements and the base course, a factor also identified by Kirschner. Bond between the upper course and the reinforcing elements need not be so great, albeit that it is invariably greater than that bond developed below. Theoretically, the prevention of movement within the lower course will have the effect of eliminating the continuation of cracks through the wearing course.

2.2 Stress relief

Research in the USA led to the derivation of a document referred to as the "Task-Force 25 Report" [4], the title of the committee responsible for the research leading to this guidance document. The majority of simple stress relief materials are non-woven geotextiles that comply with the requirements of this document, a minimum tensile strength of 1.2kN/m and minimum elongation of 50% at break. The crack (or potential cracking zone) is bridged by a material usually being of low tensile strength and high extension. Installation of these products is carried out by spraying a generous quantity of bitumen onto the lower pavement layer and rolling onto this binder, the stress relief fabric. By bridging the cracks with this layer of bitumen impregnated textile, movement stresses are transmitted laterally into the body of the interlayer and absorbed. Contrary to the previous case, the interlayer does not eliminate movement, but theoretically, dissipates its' effect, preventing any cracking continuing into the upper course. Bond between the interlayer and the overlying and underlying courses tends to be equal. This method has the secondary (but also significant) function of waterproofing the pavement, reducing the amount of water that may reach the lower pavement layers, possibly reducing movement.

3 Alternative practice

3.1 Reinforcing stress relief materials

Opinion is divided on which of the two methods above give best results in retarding reflective cracking. A small number of manufacturers of geotextile type products have researched this subject more closely although a definitive answer as to whether stress relief or reinforcement materials have the greater effect in retarding reflective cracking will obviously take some considerable time to discern with ongoing trials taking several years to yield results. It has been the intention of Don & Low Ltd to address this sector of the market by offering a product which fulfils the essential requirements of Kirschner in terms of tensile strength (particularly at intermediate strains) and also, by its' mode of installation, offer an impermeable, stress relieving, waterproofing layer within the pavement.

Results from projects completed will take some years to yield data which can definitively prove this stance. In some projects the design thickness' have been varied as a result of the incorporation of a geotextile interlayer. Walsh [1], suggests that a fabric may be appraised as an equivalent to a given thickness of "x" mm of asphalt and this approach is commonplace in the USA but if this type of comparison is used to actually amend the design, the effect of the fabric cannot be accurately measured against any previously accepted construction.

3.2 Arguments for and against reinforcing and stress relief materials demonstrating the need for combination materials

Opposing proponents of each method currently use arguments as follows;

Stress relief fabrics do not contribute significantly to the structural stability of the pavement. Their tendency to exhibit large elongation under relatively low tensile loads means that they will allow unacceptable deformation of the overlying course(s). The ability to absorb movement stress is therefore only argued to be effective as long as the stress is transferred directly to the bitumen layer, relying on the fabric only to retain the bitumen in intimate contact with the cracking zone. These fabrics tend to be lightweight non-woven materials, callendered to a varying degree. Their structure allows them to readily absorb the bitumen on which they are laid but also makes them weather sensitive after they have been laid down in so far as they will also absorb rain or surface moisture - undesirable in Northern European climates.

The contrary view;

Reinforcement fabrics are reliant on an inherent rigidity (high tensile strength and low elongation) for their ability to effectively join and hold together the cracks beneath them. This inelasticity is incompatible with bituminous material that may expand and contract greatly in the variances of seasons and daily weather changes. The bond between reinforcing elements and the course beneath can rarely match that achieved by the stress relief fabrics, yet Kirschner suggests this is an important contributory factor to its' success in use. The refinement of some of these products to include a bitumen coating to the reinforcing elements intends to allow a bond to develop when the asphalt paved onto it heats the bitumen and this bonds with the layer below. Tests to determine the adhesion of grid to pavement are prescribed but it is argued that surety of the same degree of bond *after* paving is difficult to obtain. In damp or cold weather this bond is minimal or non-existent and the material may at the end of the paving process, be bonded efficiently only to the overlying course. The areas where two sheets lap is even more problematic as these materials are not prone to bond to themselves. Cores extracted from sites where these materials have been laid demonstrate this lack of bond and this obviously has ramifications for the lateral transmission of tensile strains across overlaps that these materials are designed to achieve. Obviously, even if they work in their own roll width, they will not perform as well (if at all) in their overlap areas. For this reason, some geogrid manufacturers recommend that adjacent widths are mechanically joined together. The reinforced wearing course may be effectively bonded to the base course at the time of installation but when expansion or contraction of the pavement occurs, albeit minimal, it may be expected that a shear plane may develop on the plane of the weakest bond since the wearing courses' expansion or contraction will be influenced by that of the reinforcement. In this event the courses above and below the reinforcement may move independently, accelerating the fatiguing of the pavement. Reinforcing grid type materials may, in some cases, have a "medium" elongation allowing more expansion and contraction but their effectiveness will still be governed by their ability to adhere to the lower course. This may have to be achieved by nailing and tensioning the product to the lower course this making installation slow and costly.

Both arguments have some substance. The position of an Engineer will be determined by considering these arguments and with local knowledge of the nature (and cause?) of the reflective cracking on his project, deciding which solution is most likely to succeed. It seems to be apparent incidentally that most Engineers do tend to strongly favour one particular argument although neither can be categorically proved a more accurate representation than the other.

Reinforcing stress relief materials have become available in response to this dilemma with the aim of combining the benefits of each method of crack retardation. Fig. 2 shows the relationship between tensile strength and elongation under load for various types of interlayer. It highlights the fact that these "combination" products perform in the middle ground between the high tensile strength/minimal extension reinforcing products and the minimal tensile strength/high extension stress relief products. Kirschner (section 2.1), in identifying the characteristics required of an asphalt reinforcement, determined that the ideal properties of such a material should be as below (i.e. lying above the "Kirschner line").

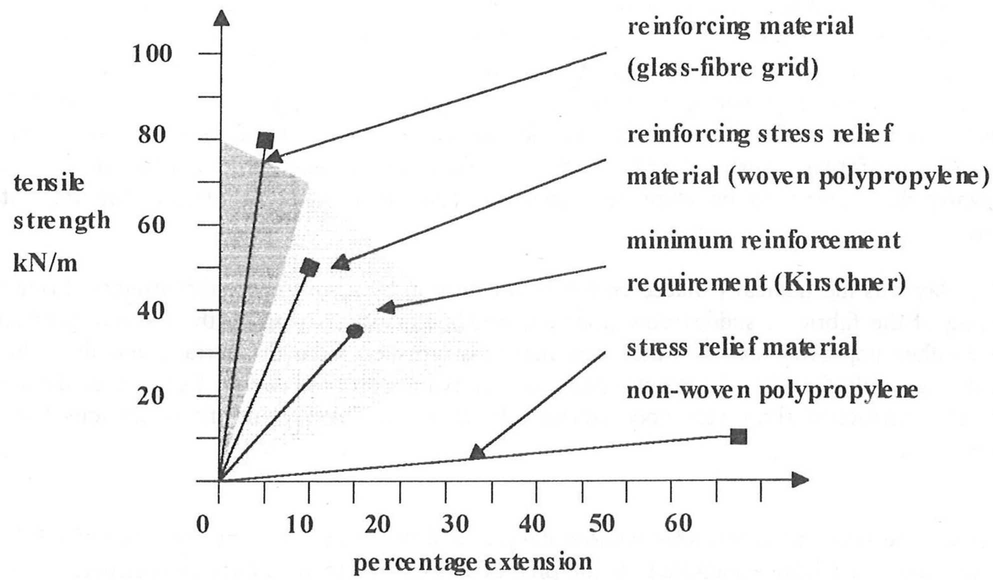

Fig. 2 Relationship between tensile strength and elongation in pavement interlayers and the resultant effect

It may be argued that choice between stress relief and reinforcement need not therefore, be simply one or another but the Engineer who perceives benefits from both types of interlayer can now use a combination material such as that which Don & Low Ltd have sought to offer in their Lotrak Pavelay product. Several types of combination material exist. The basic principle is that the material should be a close textured fabric that can be laid on a tack-coat of bitumen in the same way as a simple stress relief fabric but that it should have reinforcing tensile strength at a lower extension. This type of material embodies the benefit of reinforcing fabrics, stitching the two sides of a crack together by virtue of the high tensile strength. Its bond to the lower course should be much more efficient due to its application onto the bitumen tack-coat and the heat transmitted to the bitumen through the fabric when paving commences ensures that the bond with the course above is efficient also. The extension of these materials tends to be greater than the plain reinforcement materials made from glass fibre or steel, minimising the risk that additional stresses are induced in the pavement in thermal expansion or contraction. These materials also act in the same way as the simple stress relief fabrics by allowing lateral transmission of movement stresses into the fabric and the surrounding bitumen.

The question must then be posed, does this type of interlayer perform satisfactorily in reducing or eliminating reflective cracking? The most important factor in a successful installation is that the material must be laid by a competent installer. The surfacing contractor may wish to lay these materials but optimum results will be attained by using a subcontractor who specialises in this type of work and is aware of the limitations of each material available.

Trials have been carried out by Don & Low on a variety of projects, using the Lotrak Pavelay woven polypropylene interlayer. This material acts to reinforce and to relieve stress. The initial findings of these trials are documented below.

4 Site experience

The need for a reflective cracking inhibitor was identified in the reconstruction of the high speed test track at the Motor Industry Research Association (MIRA), Nuneaton, England. The track is constructed over concrete slabs from an old airfield and in the past has seen previous overlays affected by reflective cracking from the concrete base as soon as 18 months after overlaying.

In reconstruction, the track was reduced to the concrete slab and a bituminous regulating layer laid to achieve required levels, followed by the normal base course and wearing course construction. To reduce the chance of reflective cracking recurring, MIRA specified the inclusion of a geotextile interlayer at the interface of the regulating layer and the base course. MIRA, after considering various product types together with their associated benefits, recommended the use of a reinforcing stress relief material. The woven polypropylene Lotrak Pavelay product was selected due to its ability to act both as a stress relief membrane and a reinforcing fabric. In addition, comparison of the installed product costs showed the woven polypropylene fabric to be more cost effective than other materials offering the requisite characteristics.

Lotrak Pavelay was mechanically placed on a K1-70 emulsion by a specialist subcontractor. Prior to the overlaying of the fabric, a sudden downpour left puddles of water lying on the Pavelay product. When the weather improved, excess water was manually brushed from the surface and the fabric allowed to dry naturally for 15 to 20 minutes prior to overlaying with base course. Cores taken through the completed construction show very good adhesion between the Pavelay and the bituminous layers above and below it.

A short control section was constructed without Pavelay and the comparative performance of the two types of construction are being monitored. At the time of writing, 17 months after reconstruction, both sections are in a good condition with no sign of reflective cracking.

At the time of initial trials in 1991, the A85, Crieff Road trunk route in Perth was found to be showing unacceptably extensive levels of cracking along its length. This was judged to be due to a combination of increased traffic loadings and earlier work by public utilities. Settlement of the trench material had resulted in the cracking of the asphalt courses at the edge of the service trench and also at other areas that had been previously disturbed. Had no remedial action been taken, the surface cracking would have allowed unacceptable levels of water ingress into the foundation and this would have obviously led to the premature failure of the whole pavement. To reduce the possibility of reflective cracking recurring in these areas and to ensure that the pavement structure was effectively waterproofed, it was decided to include a geotextile interlayer.

It was recognised that the inclusion of a geotextile would not speed the maintenance scheme but if it allowed the road to remain serviceable for a longer period of time, this would have cost benefits in more ways than one. The cumulative re-laying cost of the road would be reduced but in addition, closure of this busy road in Perth would require the diversion of large traffic volumes onto more minor and less suitable carriageways, having a detrimental effect on these routes also. It was therefore decided that the use of a woven polypropylene interlayer, Lotrak Pavelay, offered the best prospect of extending the maintenance cycle at a cost that could be justified.

Tayside Contracts, the contracting arm of Tayside Regional Council, carried out the repairs to Crieff Road. The existing levels were reduced by cold-planing to a depth of 100mm, leaving a sound laying surface. A K1-70 emulsion was sprayed onto the carriageway and the Pavelay was brushed onto this tack-coat when the water had evaporated. Successive layers of 60mm of hot-rolled asphalt (HRA) base course and 40mm of HRA wearing course were laid to, or close to, the original levels. Four and a half years later, there is no sign of reflective cracking.

In both of the above cases the absence of a failure in the repair sections to date precludes any conclusions being drawn as to the lifetime extension attainable by this type of product. It is the case that all of these products have been used for too short a time in Europe for any Engineer or manufacturer to determine the average lifetime increase with any degree of accuracy. The material laid over the Pavelay in the above cases was asphalt. It is not uncommon to see very high delivery temperatures for asphalt today; improved insulation of delivery vehicles has made temperatures in excess of 175°C commonplace. Since the melting point of polypropylene is 167°C, it is occasionally perceived as a problem that asphalt temperatures may exceed this figure. On site trials by Don & Low Ltd., the manufacturer of Lotrak Pavelay have found similar results where asphalt temperatures of 175°C have led to interface temperatures of approximately 125°C. The relatively low temperature of the fabric (at or close to ambient temperature) leads to a rapid cooling of the underside of the asphalt course as is normal, hence protecting the fabric from such extremes of temperature as could cause it damage.

5 Cost benefit analysis

The benefit of these various types of interlayer may be derived by relating pavement lifetime extension to the cost per square metre of each product. However, since few installations have reached the end of their useful life, and materials have not necessarily been laid with an untreated control, this measure is difficult to determine. The only measure that can be applied universally is to relate cost per sq.. m installed to the cost of the overlying course per sq.. m. The additional cost of the interlayer is therefore measurable against the cost of asphalt giving a requisite increase in lifetime to justify its inclusion in the works. This requisite lifetime increase (RLI) should then be compared with the data available to date from ongoing trials to ascertain whether it is envisaged to be attainable. The interlayers may then be further compared by a simple relation of RLI to anticipated actual lifetime extension. Using a *notional* price per sq. m of £6.00(sterling) to lay asphalt wearing course on a small to medium site and comparing to an untreated control with an estimated lifetime of, say, five years, table 1 illustrates the above analysis.

Table 1 Requsite lifetime extension in relation to notional asphalt cost of £6.00/m² and untreated control lifetime of five years

	Product	Cost per sq.m. installed (£)	Requsite lifetime increase	Actual lifetime increase required
Stress relief materials	A	£1.50	25%	1yr 3mths
Reinforcing /	B	£2.00	33.33%	1yr 8mths
stress relief	C	£3.50	58.3%	2yrs 11mths
materials	D	£4.50	75%	3yrs 9mths
Reinforcing	E	£4.00	66.67%	3yrs 4mths
materials	F	£6.75	108.3%	5yrs 5mths

It is easy to envisage that the RLI s of 25% and 33.3% can be attained; data is readily available from trials which demonstrates this degree of pavement lifetime increase, albeit that these trials are in some cases ongoing and the actual lifetime increase may yet be considerably higher. An RLI of 75% however, is obviously more ambitious. It may be perfectly attainable but for example, a pavement where an untreated section was expected to last for say, five years, product **D** would need to prolong the lifetime of the pavement for more than two years after the cost of product **B** had been justified.

The Engineer must arguably show a certain amount of faith to decide which product is likely to justify itself in his project. The table above represents relative costs of actual materials, **A** representing a simple stress relief fabric, and **B, C** and **D** representing reinforcing stress relief materials. **E** and **F** represent high tensile strength, minimal extension reinforcement materials. All are currently available in the United Kingdom.

6 Conclusions

There is a large amount of confusion about how the retardation of reflective cracking is most effectively achieved. The two opposing views that stress relief and reinforcement are each themselves, the most effective methods, will probably remain for some time to come. A definitive answer appears to be difficult to prove.

Work to date using materials which combine the benefits of each system has offered encouraging results although this is insufficiently well developed to yield a clear proof of the superiority of these materials. However, since some of these materials have installed costs at levels close to the simple stress relief fabrics, their ability to further retard reflective cracking by their additional reinforcement function makes further trials and appraisal technically and commercially worthwhile. There have been early failures in all three categories and it must be borne in mind when designing the scheme, that the object of the exercise is to lengthen the maintenance cycle at a cost that can be justified in extra pavement lifetime. An expensive product may be expensive by virtue of the technology employed in its manufacture, not because it can necessarily offer commensurately high performance. The Engineer is almost invariably in a position where his design must be justified on technical merit and cost and an exercise in cost benefit analysis (such as in section 5) is essential in appraising the materials on offer.

Reinforcing, stress relief materials offer the Engineer an alternative to the two types of simple, one-purpose materials without compromising effectiveness in either function. Their use is forecast to increase.

7 References

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