DESIGN GUIDE FOR ASSESSMENT, TREATMENT SELECTION AND MINIMISATION OF CRACKS ON COMPOSITE AIRFIELD PAVEMENTS IN THE UK - 2003

S. J. ELLIS
TRL Limited, Crowthorne, UK
sjellis@trl.co.uk

J. COOK
Ministry of Defence, Sutton Coldfield, UK
John.Cook@DE.MOD.UK

ABSTRACT

In the UK the Ministry of Defence and TRL have been working together since the late 1980s to reduce the impact of reflection cracking on military airfields. Reflection cracking affects pavements to a greater or lesser extent at over 85% of MOD airfields. The reflection cracking predominantly occurs in overlays to rigid pavement structures and in a less pronounced nature in the asphalt surfacings to semi-rigid pavements and also due to movements at cracks or lane joints in underlying age-hardened asphalt. This in turn necessitates a substantial amount of recurring maintenance/ restoration works in order to ensure safe aircraft ground operations.

The studies have involved full-scale trials of alternative anti-reflection cracking techniques, monitoring of their long term performance and the detailed site investigation of reflection cracking occurrences to establish the most appropriate maintenance / restoration treatment. This culminated in the development of a design guide. This paper summarises the design guide providing information on: the level of site investigation required in order to appropriately evaluate reflection cracking, categorisation of the severity of reflection cracking, and the medium- and long- term design options for subsequent pavement rehabilitation.

The design options include varying overlay thicknesses, alternate surfacing options (Marshall Asphalt versus porous friction course), crack and seat maintenance and the use of geogrids. A brief summary is provided of the supporting evidence for these design options that developed from the long-term performance monitoring of full-scale trials.

KEY WORDS

SEMI-RIGID PAVEMENTS / REFLECTION CRACKING / AIRFIELD PAVEMENTS / DESIGN / MAINTENANCE.

1. INTRODUCTION

In the UK the Ministry of Defence and TRL have been working together since the late 1980s to reduce the impact of reflection cracking on military airfields. Reflection cracking predominantly occurs in overlays to rigid pavement structures and in a less pronounced nature in the asphalt surfacings to semi-rigid pavements and also due to movements at cracks or lane joints in underlying age-hardened asphalt. This in turn necessitates a substantial amount of recurring maintenance/ restoration works in order to ensure safe aircraft ground operations.

In conjunction with an extensive long-term research programme a design guide has been developed. The research has involved full-scale trials of alternative anti-reflection cracking techniques, monitoring of their long term performance and the detailed site investigation of reflection cracking occurrences in order to establish the most appropriate maintenance / restoration treatments. This paper summarises the design guide and in particular discusses the importance of appropriate site investigation techniques and interpretation thereof. Also discussed is the procedure once diagnosis of reflection cracking has been made, the design guide introduces categorisation of the severity of reflection cracking, and medium- and long- term design options for subsequent pavement rehabilitation.

A brief summary of the full-scale trials that have provided the evidence for the design options is also provided.

1.1 Background

Many of the pavements on the military airfields that the Ministry of Defence are responsible for are of composite construction comprising 1940s and/or 1950s concrete pavements with multiple blacktop overlays that have periodically been applied as expedient maintenance treatments. Reflection cracking has progressively occurred at the surface through many of the blacktop overlays as a consequence of movements at the joints or cracks in the underlying concrete layer(s). Reflection cracking of a less pronounced nature has also occurred in blacktop surfacings due to movement in underlying cement-bound bases (eg.: pavements with ‘semi-rigid’ construction) and also due to movements at cracks or lane joints in underlying age-hardened asphalt.

Maintenance / restoration treatments for reflection cracking can vary considerably in cost depending on several factors. These include the degree of reflection cracking, the operational requirements and the performance of the maintenance treatment. Further complications are: the degree of proven performance of maintenance treatments which is somewhat variable, new treatments that continue to be developed, as do the extent and severity of pavement defects other than reflection cracking. The design guide has been developed in order to provide guidance on the use of various cost-effective treatments based on the investigation of reflection cracking problems at airfields and the performance of full-scale trials to evaluate anti-reflection cracking techniques.

The design concept in the guide has been prepared as a reflection cracking planning procedure with a systematic step-by-step route through:

- Site investigation of existing surface cracking.
- Assessment of the reflection cracking problem.
- Selection and design of maintenance treatments.

1.2 Reflection cracking

Understanding the mechanisms of reflection cracking is an important part of being able to design for maintenance and or minimisation. For many years, jointed unreinforced pavement quality concrete has been used to construct airfield runways and taxiways at MOD airbases. Historically, for UK military airfield construction, the standard practice has been to omit load transfer dowel bars between adjacent concrete slabs. Although single-slab construction is usually employed, in the 1950's twin slab construction was sometimes specified for use at airfields from which heavy aircraft operated. In the twin-slab construction the joints of the top layer were offset to those of the bottom layer and a separation membrane was usually specified to be laid between the two layers.

In areas where jet blast and fuel spillage are not a major consideration, asphalt overlays have provided an economic means of restoring or improving pavement life. After a few years in service, reflection cracks generally start to occur in the surface of the asphalt overlay above the joints between the concrete paving slabs due to the thermal movements in the underlying concrete. Reflection cracks also occur in the surface of semi-rigid pavement construction which is frequently used on taxiways. This type of construction employs base layers comprising a continuously laid cement-bound layer under an asphalt base layer and an asphalt surfacing. Crack initiation has been described as occurring in the surface of the asphalt and propagating downwards to the joint in the concrete pavement or to the transverse shrinkage crack in the cement-bound base. Three mechanisms of cracking were identified by Nunn (1989). The first and most classical theory of the cause of reflection cracking is cracks produced as a result of horizontal movements between adjacent concrete slabs when they expand and contract under the influence of daily and seasonal temperature changes. These movements induce high tensile strains in the asphalt directly above joints or cracks in the underlying concrete that may initiate a crack in the asphalt, which then propagates up to the pavement surface. A second theory is that a reflection crack can be induced as a result of vertical movement between adjacent concrete slabs under the action of a wheel load, due to a lack of foundation support. Shear stresses are generated in the asphalt that could cause the crack to propagate to the surface. Clearly, in both mechanisms where cracks propagate upwards, the rate of propagation depends on the thickness of the asphalt overlay and on the foundation support. For many years, it was widely accepted that reflection cracking was caused solely by a combination of these two mechanisms. For the third theory cracks start at the surface of the asphalt caused by a combination of thermal contraction and warping of the pavement under cold Winter conditions, when the asphalt is brittle and least able to accommodate tensile strain caused by thermal contraction. This effect increases with time because the asphalt near the surface ages and becomes more brittle.

Extensive investigations into reflection cracking in semi rigid and overlaid jointed concrete road and airfield pavements by coring has demonstrated that, in the UK, cracks do in fact initiate at the surface of the asphalt and propagate downwards to join up with the underlying joint or crack in the concrete. The initiation of cracks has been found to depend on the temperature cycle, thickness of the asphalt and on the properties of the asphalt surface layer. More ductile surfacing materials, with a higher yield strain and higher recovered binder penetration, were found to contain fewer reflection cracks. In many instances, particularly for overlays thicker than 150mm, reflection cracks visible at the surface often do not penetrate the full depth of the asphalt layer. The studies concluded that crack propagation was dependent upon:

- Low temperature exposure and brittleness of the wearing course;
- thickness of the flexible layers;

- resistance of the bituminous binder to age hardening and climatic conditions; and
- temperature regime during construction and pavement life.

In the early stages of development, reflection cracks may barely be visible and are not considered to be a structural problem. However, when they propagate through the pavement, infiltration of water can weaken the foundation and fine material may be pumped to the surface, resulting in the creation of voids beneath the concrete. Traffic loading exacerbates the situation but of greater concern on airfields is the likelihood of spalling at the cracks and the potential for FOD to aircraft. In order to inhibit the occurrence of reflection cracking the MOD has for a long time recommended a greater thickness of asphalt overlay is applied than is required for structural strengthening (PSA, 1989). Although this provides an added benefit of better thermal insulation to the concrete, which helps to reduce thermal movements, it increases the cost.

2. DESIGN GUIDE

There are three main parts to the guide and they are summarized in the sub-sections below.

2.1 Site Investigation

Once reflection cracking has been identified as a problem to be solved, a detailed site investigation is required. As much data as possible should be obtained from a desktop study of construction and maintenance inspection records. The level of site investigation required will depend on the amount of information already available versus the need to fully understand the mechanism of the development of the reflection cracking.

The initial surface defect survey will have identified surface cracking as a potential maintenance problem. Unless already ascertained, a more detailed survey is required to establish the size (length), severity (width and shape) and location of the cracks. For a typical reflection cracking problem the location of the cracks will relate to the joints or cracks in the concrete slabs at depth and will assist with confirmation of the reflection cracking deterioration mode.

Through pavement investigations carried out on behalf of the MOD it has been found that there can be substantial discrepancies between construction history records and actual materials present, in particular the thickness of overlays. Therefore it is important to verify the pavement construction as one of the first steps towards understanding the reason for failure. This is ascertained by taking core samples through the entire bound pavement depth to confirm the thickness of the bituminous and cementitious layers. The crossfall of the pavement should also be considered as it may have been formed in the foundation, in the concrete layer or in the surfacing material, the latter having a large effect on the thickness of the overlay. In addition, it is not unusual for the crossfall to have been altered during a pavement rehabilitation contract and this information is unlikely to be available in the construction history record.

Core samples through the cracks should also be used to determine the crack depth and the reflection initiation mechanism i.e. joint in PQC slabs, crack in reinforced concrete, natural crack in dry lean base, joint between asphalt and PQC etcetera.

Laboratory testing of the bituminous materials to ascertain compositional and structural properties may be considered necessary if the surface cracking has occurred earlier in the material's life than would reasonably be expected. This being the case, there may be cause to investigate the contract that laid the surfacing material.

It may also be appropriate to consider the load transfer capabilities of joints and cracks and the Falling Weight Deflectometer (FWD) can be used for this purpose. The FWD can be used for two separate assessment methods, firstly, to consider the load transfer characteristics of the joints or cracks and secondly to estimate the strength of the pavement layers.

All the above techniques are quite conventional as too is the use of the Ground Penetrating Radar (GPR). However, substantial technological advances in the GPR in recent years have made it a very valuable tool when assessing reflection cracking problems. A more detailed description of the GPR and its application is provided below and has been previously reported with more detailed evidence by Ellis et al (2002).

2.2 The use of Ground Penetrating Radar (GPR) for pavement investigation

Radar is an echo sounding method where a combined transmitter/receiver is passed over the surface at a controlled speed. Short duration pulses of radio energy are transmitted into the pavement and reflections from material boundaries and embedded features, such as rebars or voids, are detected by the receiver. Sampling is so rapid that the collected data is effectively a continuous cross section, enabling rapid assessment of thickness and condition over large areas. By assessing the strength, phase and the scatter of signals it is often possible to find cracking and changes in compaction, bond and moisture content.

This method inevitably involves the collection of a large body of information - not all of which is of engineering significance. Analysis involves identifying the main elements of the structure under investigation and establishing the characteristics of its base condition. Variations in construction and condition can then be identified, enabling significant features to be mapped.

In order to provide a reliable definition of material type and to provide a definitive calibration of radio frequency velocity, core and trial pit information is usually required. The more core information that is made available, the greater the reliability that can be expected from the results of the radar investigation.

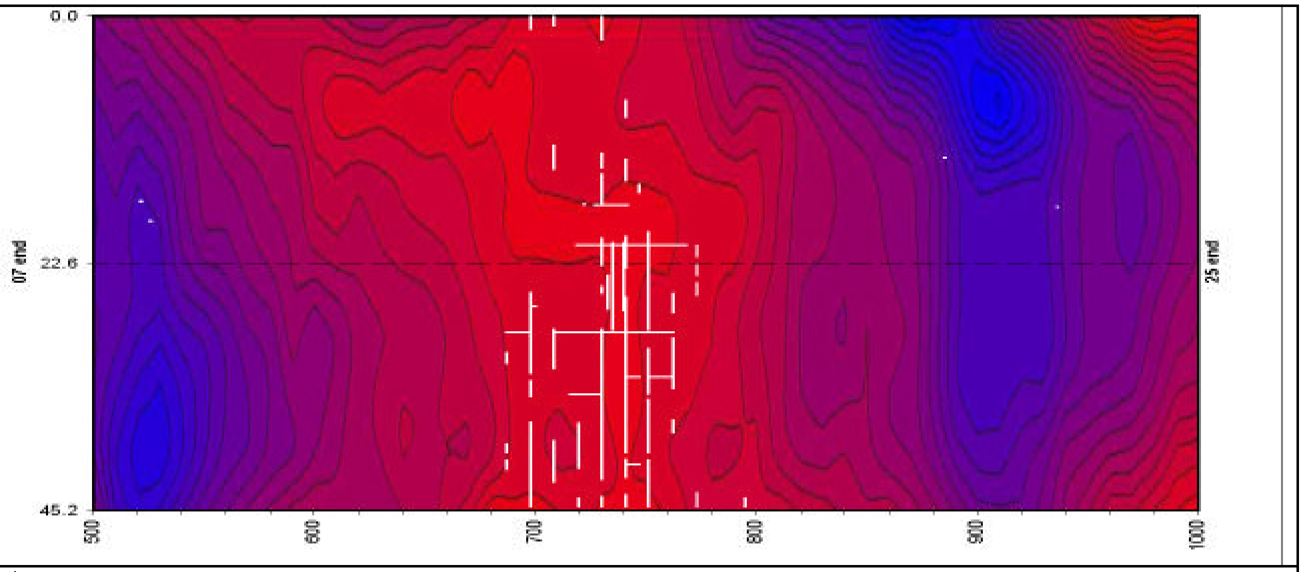
A precise match between processed radar thickness data and core logs from the same stretch of airfield pavement is not always achievable. Typically, the accuracy to which the thickness of bound materials can be measured is approximately double that of unbound or open textured materials. In these circumstances, the likely accuracy of thickness measurements is:

+/- 8% for bound layers
+/- 15% for unbound layers.

Surveys can be conducted between scheduled air traffic where necessary. In the radar recording equipment the transducers are suspended directly below the vehicle, and housed within a sled. This enables the transducers to be positioned directly on the pavement surface. The Radar control system can be set to collect around 20 scans per metre i.e. one scan every 50mm so that small changes within the pavement can be resolved, giving greater confidence to the interpretation.

A survey wheel attached to the survey vehicle provides an independent distance measurement system linked to the radar equipment. This records the position of each individual radar scan relative to a fixed starting point. A longitudinal relocation accuracy of better than ±2% measured from the nearest fixed point can be expected.

Radar data collected along the centre line of the runway can clearly show the boundaries associated with the reported construction types. The full construction of a runway can be clearly seen including well-controlled layers of asphalt over twin-slab concrete. Vairiations in sub-base material can be identified, and the joints and the expansion joints concrete slabs can be clearly defined. Particular benefits in relation to reflection cracking are clearly illustrated in Figure 1 where a visual survey of surface cracks is superimposed upon asphalt overlay thickness contour plot. The thinner areas of overlay shown in red at chainage 700-800m coincide with the observed surface crack pattern.



Notes:
1. Illustrates the relationship between overlay thickness and occurrence of reflection cracking.
2. Identifies the variation in asphalt overlay thickness.

Figure 1: Reflection cracking visual survey superimposed on GPR asphalt contour plot

When investigating surface cracking and establishing that reflection cracking has occurred it is important to establish the extent of the problem and the likelihood of progression based on concrete bay sizes and thickness of the overlay treatment. From Figure 1 it can be seen that treatment is only required in the critical areas of the thinner overlay thickness. This equates to large savings in asphalt quantities, and project maintenance duration and design life.

2.3 Assessment of reflection cracking

There are a number of factors affecting the selection of restoration treatments in order to treat and/or minimise reflection cracking. Having regard to this and the current 'state of the art' the design guidance is provided in relation to four categories of severity of reflection cracking and design / operational requirements. The concept of the category of severity of reflection cracking in the guide is an assessment of the relative stage of its development in a pavement and its potential rate of future crack propagation through any maintenance treatment. To be able to carry out a diagnostic check on the pavement it is necessary to have an appreciation of the mechanisms of reflection cracking as described in the introduction, the category of severity of reflection cracking for a pavement can only be determined if a true appreciation exists.

Once a reflection cracking problem has been identified and fully investigated the detailed information needs to be collated to establish the existing reflection crack severity. The levels of severity are identified in Table 1. The detail required to determine the severity level, which needs to have been collected during site investigation is:

- Underlying concrete bay size (m).
- Potential length of reflection cracking, ascertained from the bay size (m)
- Actual length of reflection cracking (m)
- Proportion of reflection cracking occurrence (actual/potential) (%)
- Width of reflection cracks (mm)
- Depth of reflection cracks (mm)

Table 1: Determination of reflection cracking severity level

Severity Level	Criteria Composite construction (includes surfacing where lower layer could be DLC, or asphalt joints or cracks)	PQC bay size, B (m)	Proportion of reflection cracking occurrence (%)	Crack width (mm)	Crack depth (mm)
Low	Minimal surface cracking	B < 4.5	=15.	<2.5	<40
Medium	Wide scale surface cracking		>15	<2.5	<40
		B < 4.5	>15		
		B ? 4.5	=15		
High	Wide scale surface cracking		>15	= 2.5	?100?
		4.5 = B <7.5	>1	<2.5	<40
Very High	Wide scale surface cracking		>1	= 2.5	Full depth
		B ? 7.5	>1	<2.5	<40

2.4 Selection of maintenance treatment

The design guide includes a number of considerations to be taken into account when making the selection of a maintenance or rehabilitation treatment. There will invariably be a number of other failures (eg: pavement defects other than reflection cracking such as strength and surface characteristic requirements and any site possession constraints), and these are outside the scope of the guide. Instead, the guide divides its reflection cracking considerations into design categories:

- minor maintenance,
- major Restoration Works – Low severity reflection cracking in the long term,
- major restoration Works – Low severity reflection cracking in the medium term and Medium severity in the long term, and
- other design considerations

The strategy in respect of aircraft operations and maintenance costs may determine that the requirement for a restoration project is to negate future reflection cracking in a pavement. This being the case, with the current state of the art including in-service performance records, the only reliable solutions are likely to involve reconstruction of the existing pavements or the provision of a thick concrete overslab. In the main, the best recommendation is preventative maintenance/ restoration works that can often provide the lowest whole life pavement costs. For example, this could be considered for reflection cracking whereby the bituminous surfacing is planed off during the early stages of topdown cracking and is replaced, rather than at a later stage where a more comprehensive maintenance programme may be required.

The design recommendations included in the guide are presented in Table 2, where, for a given the severity level that has been diagnosed from the site investigation, options are given for medium term and long term design lifes.

Table 2: Design options for minimisation of reflection cracking in the medium term and long term

Severity level	Medium Term Design Life (10-15 years) R=<15%	Long Term Design Life (15-25 years) R=<15%
Low:	40mm overlay on strip repairs or 80mm overlay	160mm overlay or 80mm asphalt + PFC
Low Medium	140mm overlay	220 asphalt or 140mm asphalt + PFC
Medium:	200mm overlay or	280mm asphalt or 200mm + PFC or Crack and seat and overlay (Langdale et al, 2003)
High:	Crack and seat and overlay (Langdale et al, 2003) or Geogrid + overlay (consult MOD).	Crack and seat and overlay (Langdale et al, 2003)
R = Reflection cracking occurrence (% of total potential reflection cracking) Asphalt surfacing Marshall unless otherwise stated.		

Table 2 represents a framework for design options. As previously stated, there are continuous developments in anti-reflection cracking products and techniques, and there is also an increasing availability of performance data on new techniques. At the present time, Langdale et al (2003) is a comprehensive design, construction and site supervision guide for the use of crack and seat on airfield pavements. Currently there is no definitive guidance for the use of geogrids, but their potential is recognised and the reference to consultation of the MOD is to ensure that the latest information, technology and guidance is used when they are considered as an option.

3. MONITORING OF FULL-SCALE TRIALS

The conventional overlay material used at UK military airfields is Marshall Asphalt (MA) with or without a Friction Course (FC) surface layer and these are the materials that have been used in most of the trials. The anti-reflection cracking methods and the materials used in the trials have included: geogrid reinforcement, stress absorbing membrane interlayers (SAMIs), modified asphalt overlay, alternative asphalt overlay materials, crack and seat treatment to the concrete, and asphalt inlay over concrete joints. The details of anti-reflection cracking treatments that have been assessed through full-scale trials are summarised in Table 3. The performance of the trials is summarised in Table 4.

Table 3: Design and construction details of anti-reflection cracking trials on UK military airfields

Airfield/ /Construction Date	Section	Treatment	Overlay Material	Overlay Thickness (mm)	Existing Construction
Finningley March 1989	T1 T2 T2/3 T3 T4 T4/5 T5	Fibrescreed FC layer MA control DBM layer SBS MA MA control Fibrescreed	MA+FC MA+FC MA+FC MA+FC SBS MA MA MA	120 140 120 120 40 40 40	2-layer JCP on shale Slab size: 3mx3m HRA on lean concrete
Northolt Aug. 1993	S1 S2	Glasgrid Control	MA MA	100 100	HRA on JCP on hoggin
July 1997	S3 S4	BituforTM Control	MA MA	70 70	JCP on unbound subbase
Brize Norton July 1994	T1 T2 T6	SBR MA EVA MA Control MA	SBR MA EVA MA MA	40 40 40	MA on rolled dry lean concrete
Aug. 1994	T3 T4 T6	Glasgrid HaTelit Control	MA MA MA	100 100 100	The grids were installed within the overlay
Marham Aug. 1995	S1 S2 S3	Asphalt Inlay	UL-M Safepave Slurry	23 21 5	Marshall asphalt on JCP
Coningsby Sept. 1996	S1 S2 S3 S4	Control C&S (1m) C&S (0.5m) C&S (0.75m)	MA MA MA MA	150-210 150-210 150-210 150-210	2 layer JCP on unbound granular subbase Slab size 3mx3m
Lyneham December 1996		C&S (2m, 1.5m, 1m, 0.75m)	none		JCP on lean concrete Slab size 6mx3m
Sept. 1997 (full rehabilitation contract)		C&S (1.2m)	MA	170	JCP on lean concrete or asphalt Slab size 6mx6m/6mx3m
MA - Marshall asphalt FC - Friction Course HRA - hot rolled asphalt SBR – styrene-butadeine-rubber SBS - styrene-butadeine- styrene EVA – ethyl-vinyl-acetate C&S - crack and seat, (crack spacing) JCP - jointed unreinforced pavement concrete					

Table 4: In-service performance of anti-reflection cracking trials on UK military airfields

Technique	Location	Performance
Crack and seat	RAF Coningsby	No reflection cracks in test or control sections after 7 years.
	RAF Lyneham	Taxiways, 5 years since maintenance, no reflection cracks to date.
Geogrid	RAF Northolt	Glasgrid installed below 100mm new Marshall asphalt basecourse and wearing course – needs to be laid on smooth surface, significant cracking after 8 years (30-40%). The length of transverse cracking per linear metre of taxiway is the same as the control.
	RAF Northolt	Mesh Track installed between concrete and 70mm Marshall asphalt overlay, severe cracking within 6 months, not recommended. A complete bay pattern above large slabs, fewer above 3m x 3m slabs.
	RAF Brize Norton	Glasgrid and HaTelit installed, after 8 years test sections showing fewer cracks than associated controls.
Geogrid	RAF Finningley	Fibrescreed on top of new basecourse performing not better than the associated control section, though there is no detailed information available to confirm that the Fibrescreed was correctly installed.
		Fibrescreed joint repair under the centre-line and SBS modified Marshall asphalt work – significantly less cracks than control.
Friction course	RAF Finningley	Friction course on Marshall asphalt on DBM basecourse – slightly delays cracking compared to control. Friction course prior to regulating gives significantly better results than the control.
Asphalt inlay over joints	RAF Marham	After 8 years cracking at trench edges: full with slurry seal and partial with the thin wearing courses.
Modified asphalt	RAF Brize Norton	Brize Norton – Marshall asphalt wearing course incorporating SBR and EVA modifier, after 7 years, modified asphalt same as control, with reflection cracks.

From the in-service performance monitoring the following conclusions and recommendations were made:

1. Use porous friction course as the surfacing material on runways.
2. Use crack and seat.
3. Look at modified wearing courses in more detail.
4. Develop a threshold thickness of overlay in relation to concrete bay size.
5. Consider an appropriate method to design and evaluate geogrids.

4. CONCLUSION

Surface cracking has been a problem for the MOD for many years. In more recent years an understanding of cracking mechanisms and an appreciation of 'reflection' has allowed appropriate protection and maintenance techniques to be developed. Identifying the reflection cracking severity and the design requirements is a new method that will allow more cost effective design and maintenance solutions to be applied.

Further research is required to establish the long-term performance of some new and developing anti-reflection cracking techniques. The design guide that has been developed is a framework that will facilitate the inclusion of innovative techniques as they are verified in the future.

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