Session 4
Paper (a)

BITUMINOUS BINDERS FOR HIGHLY STRESSED CHIP SEALED PAVEMENTS

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SYNOPSIS

Chip sealed pavements rely on the rheological properties of the bituminous binder for aggregate retention and waterproofing. Stresses such as high axle loading, tyre scrub by multi-axle vehicles or temperature extremes can cause premature distress due to binder failure. The addition of thermoplastic polymers to the binder can provide sufficient rheological improvement to the binder to withstand extreme stresses. A general description of the process and technology is given.

1. INTRODUCTION

Chip seals have long been used with great success on New Zealand highway pavements. In fact, to date New Zealand has been a world leader in chip seal technology.

This situation has arisen for a number of reasons:

- the long narrow shape of New Zealand coupled with low population means we have more highway kilometers per head of population than most countries
- our isolation has provided a fertile ground for "home-grown" technologies
- our low population has meant less tax dollars per kilometer of highway, hence economical solutions are necessary to our pavement needs
- our relatively low traffic density means that most of our pavements are not subject to extreme traffic stresses

Thus chip sealing design and practice has been elevated to a high standard in New Zealand.

Further, for economic reasons most of our highway pavements are constructed using unbound granular basecourse materials. This results in relatively flexible pavements; a situation that chip seals perform well in.

Hence New Zealand has developed a unique approach to pavement construction, surfacing and maintenance that has well suited our highway needs.

2. CHIP SEALING

What is a chip seal? In essence, it is a waterproofing layer of bitumen applied to a pavement followed by crushed rock chips. The purpose of the bitumen is only to provide the waterproof seal, and the chips serve as a non-slippery trafficking surface. If no chips were applied, the bitumen seal would quickly be worn away by the traffic.

The key for effective chip sealing is to evenly apply the bitumen; enough to waterproof the pavement and hold on to the chips, but not so much as to completely submerge the chips and create a sticky, surface, dangerously slippery when wet.

This technology is well known to road practitioners in New Zealand, and is largely problem free. However, in recent years (since deregulation of the transport industry) there has been a growing number of heavy commercial vehicles

(HCVs) on our roads. These HCVs stress both subsurface pavement layers and chip seals far more than ordinary car traffic does, and this has become evident in the increasing amount of maintenance needed on the State Highway network. In other words, the increasing traffic counts, and numbers of HCVs is pushing chip seals to, and beyond, their limits.

3. BITUMEN

The limiting factor in chip seal performance is the bitumen. In order for a chip seal to perform satisfactorily over its design life, the bitumen must:

- continue to provide a waterproof layer; ie. must not crack
- be sufficiently tough to hold the chips in place against tyre dislodgment forces
- accommodate the normal deflections found in flexible New Zealand pavements
- accommodate seasonal temperature changes. It must not become too soft in summer, nor too hard and brittle in winter
- not age harden or fatigue

It is thus evident that the increasing stresses imposed on chip seals by HCVs are pushing the bitumen beyond its limits. This is clearly demonstrated on private forest roads where logging trucks loaded in excess of that permitted on state highways rapidly destroy chip seals designed in accordance with conventional methods.

This is not to say that chip seals can not be used to surface highly stressed forest roads; they can be. For success, it is necessary is to modify both the design procedures and the bitumen to withstand the demands placed on them by heavily laden logging trucks.

Distress shown by chip seals constructed using conventional wisdom is due to the extreme axle loading of the logging trucks, and tyre scrub from multi-axle units on corners. The high axle loadings cause rapid embedment of the chips into the substrate, exposing the bitumen to truck tyres. The bitumen is then picked up by the hot tyres and tracked down the road, often leaving areas of exposed basecourse which rapidly develops into potholes. In other words, the waterproofing integrity of the seal is lost.

In addition, tyre scrub from heavily laden multi-axle vehicles on corners can completely remove chips from the seal, exposing the bitumen resulting in the problems described above.

The surface enrichment caused by chip embedment into the underlying pavement layers can be prevented by using less bitumen; this is common practice when designing chip seals for highways. Bitumen application rates are adjusted to compensate for traffic counts: less bitumen is applied where traffic densities are high.

Unfortunately, the less bitumen applied to the road surface, means greater demands on its tensile strength. In other words, if less "glue" is used, it will take less force to dislodge the chips.

Where vehicle loadings and stresses are severe, such as on forest roads, the model breaks down. To prevent surface "fatness" (enrichment), bitumen application rates must be reduced below that which is necessary to hold the chips. Conventional bitumens are not adequate for the task.

It is possible to use harder grades of bitumen for increased strength, but in cold conditions these hard materials become very brittle, are prone to cracking and chips can be "snapped" out of the seal by tyre forces. Furthermore, these hard grades of bitumen have reduced lifetimes as they undergo accelerated aging during the manufacturing process. Thus seal life is reduced.

In summary, we need bitumen binders with increased tensile strength and toughness, flexibility in the cold and which do not melt in the heat.

4. MODIFICATION

The bad news is that ordinary bitumens are not available with suitable physical (rheological) characteristics for extremely stressed conditions such as those found on forest roads. The good news is that bitumen rheology can be enhanced by the addition of polymeric additives based on synthetic thermoplastic rubbers, such as Technic Industries' Techniflex PMB100.

These bitumen modifiers enhance the rheological properties of bitumen in several ways:

- toughness is improved
- high elasticity is added
- temperature susceptibility is reduced
- fatigue life is increased

These rheological enhancements can be discussed under the headings listed above:

4.1 Toughness

Increasing the toughness of the bitumen binder confers benefits in two ways: it enables less binder to be used, or provides for better chip retention under severe tyre stresses. In the case of highly stressed forest roads, reducing the application rate of the binder means that surface enrichment is greatly reduced. In addition, the tougher binder better resists the embedment forces imposed on the chips, hence further reducing the chances of flushed, fatty surfaces occurring.

4.2 Elasticity

The highly elastic nature of bitumen binders modified with thermoplastic rubber enables chips to "give" under high stresses, but recover to their original position when the stresses are removed. Unmodified bitumens usually have some "give", but do not have the elastic recovery necessary to retain the chips in position. Hence stresses sufficient to move chips in an unmodified bitumen seal will eventually permanently dislodge the chips, resulting in exposed bitumen surfaces.

Further, the flexible nature of unbound granular basecourse pavements means that the seal undergoes significant deflections under traffic; the heavier the traffic, the higher the deflections. Therefore, adding elasticity to chip seal binders will provide better tolerance of deflections under load with reduced propensity to cracking.

4.3 Temperature Susceptibility

Conventional roading bitumens soften in the heat, and become hard and brittle under cold conditions. The sight of molten bitumen bleeding from a pavement on a hot summer's day is familiar to everyone.

Under normal circumstances, this softening and hardening with temperature (temperature susceptibility) causes few problems. However, under severe conditions where chips are subject to significant tyre stresses, softened or hard brittle binders result in loss of chips. If the bitumen is soft, tyre forces will cause chips to roll over, exposing their sticky underside. They stick to tyres and are plucked out of the chip seal. Eventually, the seal becomes a black sticky mess, with the few chips left being totally covered with bitumen.

In cold, frosty conditions, normal bitumens become brittle. This embrittlement results in cracking as pavements undergo normal deflections with traffic. Further, as individual chips experience normal tyre forces, the bitumen is too viscous to allow movement, resulting in chips being "snapped" out of the seal. As chips are removed, they no longer provide support to neighbouring chips, thus more and more are lost.

The addition of modifiers to bitumen (such as PMB100) adjusts the temperature susceptibility of conventional bitumens. The modified bitumens remain soft, flexible and elastic at cold pavement temperatures, and do not soften and melt in the heat. Thus the problem of low temperature embrittlement is solved without compromising the binder performance at high temperatures.

4.4 Fatigue

In a manner exactly similar to metals, conventional bitumen binders undergo fatigue failure with repeated flexure. As the prevalent pavement construction strategy in New Zealand is unbound granular basecourse with a chip seal, most chip seals do undergo repeated flexural stress cycles under traffic. In time, the bitumen binder fatigues, and cracks appear. The development of fatigue cracking is hastened when pavement deflections are high.

The addition of synthetic thermoplastic rubber modifiers to chip seal binders increases the fatigue life of conventional bitumen.

The discussion above begs the question as to why all chip seals are not constructed with modified bitumens? The answer is cost. Because materials such as PMB100 are based on imported high technology components, they are expensive. The road designer must therefore use these modifiers with care; where their use provides good value for money. Areas where climatic extremes, severe traffic stresses, difficult topography and weak pavements cause early failure with conventional bitumens are appropriate situations to use modifiers.

5. DESIGN

Normal design procedures can be used with PMB100 modified binders where traffic density and loading are not extreme. Due to the enhanced rheological properties of these materials, consideration may be given to increasing application rates up to 10% over design levels.

For exceptional sites, such as forest roads carrying logging trucks with high axle loadings, normal design methods must be used with caution. Residual modified binder application rates should probably be reduced significantly below conventional design levels as the heavy loadings will tend to embed the chips in the pavement. Only sufficient modified binder to retain the chips should be applied. The use of consultants with experience in modified binder chip seals is recommended.

6. CONSTRUCTION

Normal plant may be used for construction of PMB100 modified chip seals. However, there are some site practises which must be closely followed to prevent early failure of the seals:

- construction should take place in early summer so traffic compaction during the warmer months can take place.
- weather conditions on the day of construction must be settled, warm and dry, with pavement temperature 20°C and rising.
- clean dry chip complying with Transit New Zealand M/6 specification must be used. Wet, dirty chip will not adhere to the highly tough, elastic modified binder.
- adhesion agent complying with Transit New Zealand M/13 must be added to the modified binder immediately prior to spraying.
- chip application must follow immediately behind the binder sprayer. It is essential that chips be placed prior to cooling of the modified binder, otherwise adequate wetting and adhesion will not take place.
- compaction of the seal must follow immediately after application of the chip.

It is common practice in New Zealand to construct two coat seal systems when using modified binders, although this may not be necessary on sections of forest roads where there is no cross traffic or sideways tyre forces (such as on corners). It is recommended that a seal coat is constructed using either 16mm (TNZ M/6 Grade 3) or 20mm (TNZ M/6 Grade 2) chip, with a second "locking" seal coat using 10mm (Grade 5) applied over the top. The second seal coat layer may be constructed without a second binder application where sideways tyre stresses are not severe; the 10mm chips interlock with the coarser chips and tend to prevent dislodgment. Consulting with experienced personnel is again recommended.

7. CONCLUSIONS

The use of modified binders for both chip seal and bituminous mix surfacings is increasing; internationally and in New Zealand. This is due to reduced funding for road construction coupled with increasing traffic volumes and pavement loading.

Pavement designers are recognising the place for binders with enhanced rheological properties, which provide better value for money solutions to surfacing problem areas. In recent years notable successes have been achieved; for example, the trial sites constructed using PMB100 modified bitumen for Tasman Forestry in Kaiangaroa Forest.

It is likely that, while New Zealand road funding remains limited, that innovative and strategic systems will continue to be developed and used. Modified bitumen chip sealing now has a ten year history in New Zealand, and there is good experience in formulating, handling, applying and maintaining these materials.

Bitumen modified with thermoplastic rubbers is widely accepted for use where premature failure of conventional bitumens is likely, and it now has an extensive performance history. The use of modified binder in high stress situations is now proven, and provides better value for the roading dollar than conventional techniques.