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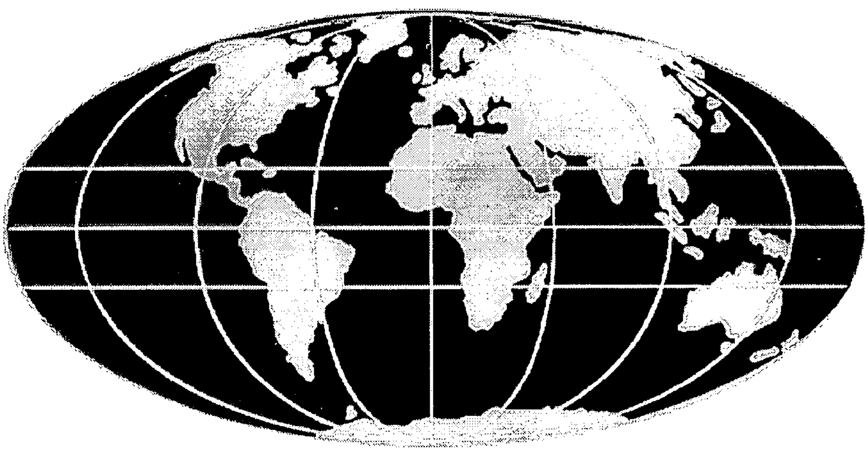

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CONDITION OF THE TAN-ZAM HIGHWAY AT KITONGA GORGE

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ABSTRACT

The causes of failure through plastic deformation in the bituminous surfacing on the Tan-Zam highway at Kitonga Gorge has been identified. Tests on core samples confirmed that in situ Voids In the Mix (VIM) had reduced to much less than the 3 per cent minimum recommended for severe loading conditions.

Difficulties arise in designing asphalt mixes for heavily trafficked roads in countries where there is limited equipment for mix design. These include selecting an appropriate level of compaction in the Marshall test and predicting the combined effect of the rates of bitumen hardening and secondary compaction. Use of a refusal density test is recommended to determine a reference density which can be used to ensure that 3 per cent VIM will be retained. To allow for secondary compaction under traffic VIM, at the time of construction will be of the order of 7 or 8 per cent. It is therefore essential to use a surface dressing (chip seal) to prevent premature 'top down' cracking which could result from age hardening of bitumen in the surface of the layer.

Ideally, performance tests are required to determine the likely performance of asphaltic surfacings, and suitable tests have been demonstrated on three mixes manufactured in the laboratory.

1 INTRODUCTION

The Ministry of Works, Transport and Communications (Tanzania) and the Transport Research Laboratory (UK) are carrying out two cooperative Research Studies in Tanzania. The TRL component of the studies are carried out on behalf of the Department For International Development (UK). One of the studies is designed to investigate the feasibility of recycling damaged premixed bituminous surfacings. As part of this project tests have been carried out on samples of asphalt surfacing from the Kitonga Gorge. This paper describes the condition of the asphalt, the reasons for the observed damage and an improved method of asphalt design for heavily trafficked roads. A large volume of very heavy commercial vehicles traverse this site. In the climbing lane towards Iringa the heavy vehicles can only move slowly, whilst for safety reasons vehicles in the down hill lane also move slowly under considerable braking. The surface of the road has become so seriously deformed that it is now quite hazardous for road users. Cars are at risk of becoming 'grounded' on raised ridges of bituminous surfacing material and the channels formed in the wheel paths carry deep water during heavy rainfall.

2 WORK CARRIED OUT AT KITONGA GORGE

In 1996 a 1km section of the Tan-Zam Highway at Kitonga Gorge, in the lane towards Iringa, was investigated. The condition of the chosen section can be regarded as being representative of the majority of the 8 km total length of the steep road section through the Gorge.

Cores were cut at 100m intervals in the verge side wheel path and at four transverse test points at every 200m. Cores were also cut across the lane at three of the most deformed locations so that the profile of the roadbase could be checked. This was done by marking sticks to equal lengths and holding a stick vertically in each hole with one end on top of the roadbase. By placing a string line across the marks it was shown that they were all at a constant height above the roadbase layer. This confirmed that no measurable deformation had developed in the layers below the bituminous material and that the failure is the result of plastic deformation within the bituminous surfacing layer.

Because of the very deformed condition of the asphalt surfacing the cores were sawn into 50mm thick 'slices' using the top of the undeformed roadbase as a reference. Bulk densities of the core slices were measured and the SG of the mixed material determined by the 'Rice' method[1]. This allowed the air voids (VIM) content of the *in situ* bituminous materials to be determined and the results are summarised in Table 1. It can be seen that VIM values were very low, some 86 per cent of the determinations being less than 2 per cent.

3 THE CAUSE OF PLASTIC DEFORMATION AT KITONGA GORGE

This section of road can be regarded as a severely loaded site, as defined in TRL Overseas Road Note 31[2], and therefore the use of the conventional Marshall mix design is considered to be inappropriate for this site.

The Asphalt Institute emphasise that a very important requirement of the Marshall test method for design of bituminous premix surfacings is;

That the level of compaction used in the test should produce the same density in the mix as will occur in the road after several years of trafficking[3].

Unfortunately the commonly used level of compaction of 75 blows in the Marshall test can grossly under estimate the degree of secondary compaction which can occur under heavy traffic. This problem is being made more difficult by increasing use of radial ply tyres and higher tyre pressures. Vehicle wheels, fitted with a cross-ply tyres tend to 'climb' out of a rut. This tends to make the wheel path wider and spreads the effect of wheel loads. Radial-ply tyres, however, tend to run in the bottom of the rut and therefore concentrate the wheel loads over a very narrow wheel path[4] .

Without detailed knowledge of the effective long term compactive effort of heavily loaded and slow moving vehicles, the choice of a set number of blows of the Marshall hammer is effectively an arbitrary one.

It is now generally accepted that 3 per cent VIM must be retained after several years of secondary compaction under traffic[2,3]. The results of work carried out by TRL in cooperation with Ministry of Works in several countries[5] are summarised in Figure 1. It is clear that there is a much lower risk of plastic deformation if VIM is more than 3 per cent after secondary compaction. At Kitonga Gorge nearly all of the found VIM values were much less than this recommended minimum and many were close to zero. This means that the original mix design did not make adequate allowance for the degree of secondary compaction which has taken place.

4 IMPLICATIONS FOR MIX DESIGN

The results illustrate that it is essential to obtain the correct volumetric composition for the traffic loading[6,7]. For conventional AC wearing courses this implies the need for a high level of quality control and detailed knowledge of material compaction characteristics at individual road sites. There will be many occasions in many countries where this will not be a realistic expectation because so many complex factors must be taken into account.

The Asphalt Institute recommends that the level of compaction to be used in the test should produce a mix density equivalent to that which will occur after secondary compaction by traffic. Effectively this means that a core cut from an AC surfacing *after* secondary compaction by traffic should ideally have an air voids content of 4 per cent and not less than 3 per cent if plastic deformation is to be avoided. To achieve this the Asphalt Institute suggest that VIM will be up to 8 per cent at the time of construction[3].

Unfortunately, in tropical environments an AC surfacing with such a high initial VIM will show premature deterioration through bitumen ageing[8,9]. An important consideration is that although compaction will occur in the wheel paths, untrafficked areas will retain the high initial air void content, especially where wheel paths are narrow as a result of the growing use of radial ply tyres. In addition, it is unlikely that the designer will be able to predict the combined effects of the rate of bitumen hardening and the rate of secondary compaction. This will be particularly difficult for roads where the vertical alignment changes frequently and, therefore, vehicle speeds, loading times and the rate of secondary compaction are variable.

Table 1 Air voids content in asphalt layers at Kitonga Gorge

Core No.	Material type	Layer height from roadbase (mm)	Bulk density (Mg/m^3)	Maximum specific gravity	VIM (per cent)
1	wc	>151	2.506	2.508	0.1
	bc	101-150	2.496	2.502	0.2
	bc	51-100	2.489	2.520	1.2
	bc	0-50	2.443	2.523	3.1
2	wc	51-100	2.516	2.509	0.0
	bc	0-50	2.515	2.535	0.8
3	wc	>151	2.531	2.532	0.0
	bc	101-150	2.514	2.523	0.4
	bc	51-100	2.502	2.510	0.3
	bc	0-50	2.476	2.502	1.1
4	wc	51-100	2.533	2.529	0.0
	bc	0-50	2.482	2.520	1.5
5	wc	101-150	2.486	2.493	0.3
	bc	51-100	2.501	2.517	0.6
	bc	0-50	2.428	2.527	3.9
6	wc	101-150	2.524	2.525	0.0
	bc	51-100	2.509	2.507	0.0
	bc	0-50	2.490	2.521	1.2
7	wc	101-150	2.524	2.532	0.3
	bc	51-100	2.495	2.514	0.7
	bc	0-50	2.401	2.569	6.6
8	wc	51-100	2.535	2.534	0.0
	bc	0-50	2.502	2.515	0.5
9	wc	101-150	2.533	2.523	0.0
	bc	51-100	2.502	2.493	0.0
	bc	0-50	2.510	2.517	0.3
10	wc	51-100	2.533	2.523	0.0
	bc	0-50	2.481	2.533	2.0
11	wc	101-150	2.529	2.528	0.0
	bc	51-100	2.521	2.517	0.0
	bc	0-50	2.444	2.534	3.6
12	wc	101-150	2.528	2.533	0.2
	bc	51-100	2.502	2.492	0.0
	bc	0-50	2.516	2.542	1.0
13	wc	101-150	2.495	2.498	0.1
	bc	51-100	2.484	2.511	1.1
	bc	0-50	2.418	2.526	4.3
14	wc	51-100	2.507	2.496	0.0
	bc	0-50	2.492	2.503	0.5
15	wc	101-150	2.503	2.512	0.4
	bc	51-100	2.498	2.488	0.0
	bc	0-50	2.509	2.518	0.3
16	wc	51-100	2.546	2.540	0.0
	bc	0-50	2.501	2.506	0.2

If the initial VIM is high and traffic loading is not severe or vehicle speeds are high, then the rate of reduction in VIM may be slow enough to allow significant bitumen hardening to take place. This may stiffen the mix sufficiently to prevent a potential reduction in VIM to less than the critical 3 per cent. If initial trafficking is both heavy and intense the subsequent reduction in VIM is likely to be sufficiently rapid to prevent appreciable bitumen hardening and mix stiffness may not increase sufficiently to prevent a critical reduction in VIM.

Because of these considerable uncertainties it is recommended that a more robust design procedure is used and that mixes which are less sensitive to errors in composition are adopted for severe loading conditions[2].

5 DESIGN OF A RUT RESISTANT SURFACING MATERIAL

5.1 Compaction and mix design

Authorities in the Middle East have recommended the use of refusal compaction as representing the ultimate density after secondary compaction on severely loaded sites[10]. This means that a mix which retains 3 per cent VIM at refusal density cannot compact further under traffic. However, to achieve this by Marshall compaction requires approximately 500 blows by the Marshall hammer to each face of the Marshall test briquette. The use of an electric vibratory hammer is preferred to extended Marshall compaction because;

- (a) It is a rapid process.
- (b) It allows a kneading action because the compaction foot is of a smaller diameter than the mould, which is more like the mode of compaction under a roller.
- (c) The compaction method is relatively insensitive to temperature and layer thickness[11].
- (d) The method offers an effective procedure for aiding quality control in the field.
- (e) Materials with a larger particle size than the maximum of 25 mm permitted in the Marshall test can be used.

The vibrating hammer test method is outlined in Road Note 31[2] and is a slightly modified form of the Percentage Refusal Density Test (PRD) procedure described in BS 598 [11]. An important feature of the test is that, at refusal density, the Voids in the Mineral Aggregate (VMA) for a given aggregate grading remains reasonably constant over the working range of bitumen content. This means that the refusal test can provide a *reference density*.

An essential requirement of a mix is that it must contain sufficient bitumen to ensure good workability at the time of construction. The effect of VMA on the relationship between VIM and bitumen content for different aggregate mixes, when compacted to refusal density, is shown in Figure 2. It is clear from the Figure that, if refusal density represents the final density after secondary compaction, the wearing course mix WC would not be a viable mix because at 3 per cent VIM and the corresponding bitumen content of about 2.9 per cent, it would not be workable. The binder course mix BC(a) would, in comparison, have a bitumen content of approximately 4.7 per cent, at 3 per cent VIM, could be expected to be workable when laid on site. Thus it is important to ensure that the aggregate structure has adequate VMA to enable it to carry a sufficient volume of bitumen.

It is generally accepted that the sensitivity of AC mixes is affected by the grading of the aggregate in the mix. If the grading follows the Fuller curve closely it is usually so dense that there is very little room for bitumen and such a mix is both difficult to compact and very sensitive to errors in composition. To make the mixes more tolerant, gradings are adjusted away from the Fuller curve. The recommendations made by the Strategic Highway Research Programme (SHRP)[6,7] can be used as a guide towards achieving this. The SHRP recommendations include a discontinuous grading envelope and a restricted zone through which the aggregate grading should not pass. The values used depend on the nominal maximum size of the aggregate. An example for a 20mm nominal maximum sized stone is shown in Figure 3. Satisfying the requirement for adequate VMA is most readily achieved with binder course or roadbase mixes with particle size distributions which fall below the appropriate restricted zone.

5.2 Transfer of laboratory design to compaction trials

After the standard refusal density, test samples of binder course which have been compacted from the loose state can be expected to have densities between 1.5 and 3 per cent lower than for the same material compacted in the road but cored out and subjected to the PRD test. This is an indication of the effect of the different compaction regime and is caused by a different resultant orientation of the particles. The differences between the densities for laboratory compaction and field samples after refusal compaction should be measured to confirm whether this difference occurs.

A minimum of three trial lengths should be constructed with bitumen contents at the laboratory optimum for refusal density (3 per cent VIM) and at 0.5 per cent above and below the optimum. The trials should be used to;

(a) Determine the rolling pattern required to obtain a satisfactory density.
(b) Establish that the mix has satisfactory workability to allow a minimum of 93 per cent PRD[12] to be achieved after rolling.
(c) Obtain cores so that the maximum binder content which allows 3 per cent VIM to be retained at refusal density can be confirmed.

For a given level of compaction in the Marshall test, VMA reduces to a minimum and then increases as bitumen content is increased. However, samples compacted to refusal density will have reasonably constant values of VMA over a range of bitumen contents before the aggregate structure begins to become 'over-filled' and VMA increases. This will means that during the trials it will be a relatively simple matter to determine the sensitivity of the mix to variations in bitumen content and to confirm the bitumen content required to give a minimum of 3 per cent VIM at refusal density. If necessary the aggregate grading can be adjusted to increase VMA which should reduce the sensitivity of the mix to changes in bitumen content.

A minimum of 93 per cent and a mean value of 95 per cent of the standard PRD density is recommended as the specification for field compaction of the layer, although obtaining higher densities would be beneficial. From these trials and the results of the laboratory tests, it is then possible to establish a job mix formula. This initial procedure is time consuming, but is justified by the long term savings that can be made by extending pavement service life and minimising eventual rehabilitation costs. After the initial work, subsequent compliance testing based on analysis of mix composition and refusal density should be a quick process, especially if field compaction is monitored with a nuclear density gauge.

Such mixes will have high VIM immediately after construction and *it is essential* to protect them from premature cracking through age hardening of the bitumen. An effective way to do this is to apply a surface dressing as part of the construction process. This provides a very thick membrane of binder at the surface which is resistant to age hardening effects and to cracking.

6 POSSIBLE TREATMENTS OF THE SURFACING AT KITONGA GORGE

This section of the road requires corrective work and it is suggested that milling is carried out to reduce the severity of the ridges in the surfacing material. It is not essential that any new material is placed on the road immediately since the milling operation would not affect the thickness of the surfacing in the wheel paths. If partial milling were to be carried out then periodic measurements of rut depths at marked test points would show if the milled surfacing was continuing to deteriorate. Bearing in mind that the roadbase is currently in good condition, considerable long term cost savings would be realised if the surfacing was replaced before structural damage occurs in the lower layers.

To rehabilitate the road satisfactory it would be necessary to remove the existing surfacing by milling. Early results indicate that leaving the bottom 40 to 50mm in place would be acceptable. This would have to be confirmed for sections of the road outside of the reported test length before remedial work is carried out. The design of a suitable bituminous surfacing material for this site must be done with care to produce a rut resistant layer.

It is thought that the existing surfacing could be recycled with approximately fifty per cent of new material to produce a bituminous roadbase for a less severely trafficked site. This is being investigated as part of the cooperative research programme between the Ministry of Works and TRL. It is estimated that this procedure would produce enough material for about 15km of bituminous roadbase.

7 CONCLUSIONS

1. The bituminous surfacing material laid on the steep section of the Tan-Zam highway in the Kitonga Gorge has suffered severe plastic deformation.

2. Air voids in the bituminous surfacing materials have decreased under secondary compaction by traffic to values which are well below the recommended minimum value. The principal cause of this is that the level of compaction used in the Marshall test for the original mix design was too low.

3. It is probable that increasing use of radial ply tyres and higher tyre pressures have produced a more aggressive loading regime which has played a part in the failure of bituminous surfacings through plastic deformation.

4. It is recommended that bituminous wearing courses on very heavily trafficked roads in Tanzania should be designed to retain a minimum of 3 per cent VIM after secondary compaction by traffic. This is in agreement with the results of work carried out elsewhere by TRL, and to the recommendations of the Asphalt Institute.

5. In order to allow for severe secondary compaction at the mix design stage it is necessary to increase the level of compaction used in the design process to more than the equivalent of 75 blow Marshall compaction. Results have shown that compaction to refusal is the only reliable reference density against which the ultimate characteristics of the mix can be compared.

6. A new design procedure has been described which should provide mixes which are resistant to plastic deformation on severely loaded sites. These mixes must, however, be sealed to prevent premature 'top down' cracking associated with age hardening of the bitumen in the surface of the layer.

7. Adoption of the vibrating hammer equipment for refusal compaction tests would involve very little additional cost. It would provide valuable addition information for the mix designer, particularly to ensure that the mix composition will be appropriate for severe loading conditions in countries where only the Marshall test equipment is available.

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