INCREASING THE SKILLS OF LABOUR-BASED CONTRACTORS THROUGH THE TRANSFER OF APPROPRIATE ROAD SURFACING TECHNOLOGY

by

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ABSTRACT

Minor roads in rural and urban areas are vital to the socio-economic well being of communities by providing access to schools, clinics, jobs, neighbouring communities and higher order roads. The provision of bituminous surfacings either as spot improvement measures or on longer lengths of road can greatly improve the wet season passability and reduce maintenance needs. In urban areas and villages there are also additional dry seasons benefits from dusts reduction. Bituminous surfacings constructed by labour based techniques are a cost effective method of improving accessibility whilst providing opportunities for increasing the skills base of emerging contractors. The paper reviews some labour based surfacing techniques which increase opportunities for the development of communities and small scale entrepreneurs.

1. INTRODUCTION

In civil engineering, there often appears to be quite long delays between the development of technology and its wide acceptance by practitioners. These delays reduce the benefits from investment in research and technological development. Much of the investment in rural road infrastructure is aimed at the alleviation of rural poverty attained through sustainable development and capacity building programmes. Traditionally, sealing technology has been an equipment intensive operation. In many cases, however, simple adaptation of these methods would enable bituminous surfacing to be constructed without the need for expensive equipment or highly skilled personnel. Adopting simple surfacing technologies increases the scope for providing all weather access if these options are used selectively to deal with areas where traffickability problems exist. These include areas where poor materials exist or the terrain is difficult. The inclusion of sealing technology within the skills base of small-scale contractors and local consultants also has engineering, financial, social and environmental benefits. The main purpose of this paper is to raise awareness of the technologies available to local contractors and consultants for provision of low cost bituminous seals constructed using labour-based methods so that these technologies can be put into practice.

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2. LABOUR-BASED ROAD CONSTRUCTION

Between 70 and 80 per cent of the road network in Africa is unpaved. Although the situation varies substantially in different countries, most roads in the rural areas are of earth construction with some of the busier roads having a gravel wearing course. In many peri-urban areas too, it has been accepted that the appropriate standard of construction should be unpaved. Increasingly, many of these roads in southern Africa and elsewhere are being successfully constructed and maintained by labour-based methods. In more recent years labour-based methods have also been seen as an important route to allow the entry of emerging contractors into the road sector. The main reason for this approach being successful is that by using labour-based methods, the level of investment required by the contractor is reduced when compared with the size of investment that would be required for a more equipment intensive operation. Using labour-based methods it is also possible for contractors to enter the roads sector at different levels of operation ranging from petty contracting for routine maintenance, to periodic maintenance, rehabilitation and larger construction contracts. With the thrust towards decentralisation evident within countries in the region, it is important to have contractors who can operate at the local level without incurring large mobilisation costs for relatively simple works.

As unemployment continues to grow within the region and the world generally, the use of local resources becomes increasingly attractive not only in financial terms but also in social terms. By adopting labour-based methods, temporary employment can be offered to people in rural areas who are generally far from other work opportunities. The development of locally-based (district and province level) contractors can assist in spreading the employment opportunities into all areas of a country, and provide capacity at the local level for the implementation of road maintenance and improvement works. This is particularly important as the emphasis shifts away from road construction towards maintaining existing road investments. This inevitably results in less new construction work being undertaken and an increase in the need for maintenance and repair works.

In many rural areas the focus on road provision may move away from the concept of vehicle operating costs and travel time to that of all weather access. When access is treated as a priority, (i.e. to schools, clinics, markets, transport services etc.), it is likely that there will be an increased focus on spot improvement solutions. If spot improvement works are to be carried out, then the conventional equipment based approach becomes expensive and cumbersome for the small sections of work to be tackled thus creating a further opening for labour-based methods using locally based contractors.

3. LABOUR-BASED SEALED SURFACES: GENERAL CONSIDERATIONS

Properly planned and supervised labour-based methods assisted by appropriate equipment can produce rural roads of a good technical standard suitable for carrying relatively low volumes of traffic. Regardless of the method of construction, there are circumstances where unpaved roads (or sections of road) are susceptible to rapid deterioration or give problems of passibility.

Some typical examples are:
a) Areas where the available soils or gravels are of poor engineering quality
b) In steep terrain
c) The land is low lying and liable to flooding

d) Traffic levels (motorised and non-motorised) are relatively high
e) In villages and peri-urban areas.

In circumstances such as these, the traffickability and passibility could be greatly improved by the application of a low cost seal.

It is becoming more widely accepted that sealed roads, providing all weather access, can be constructed at much lower costs if appropriate design standards and maintenance methods are adopted. Substantial savings can be achieved by adopting spot improvement methods and other innovative and cost effective solutions such as "design-by eye" geometrics, low-cost improvements to drainage, use of "lower-standard" materials in the pavement structure and alternative surfacing techniques suited to the region and which use locally available materials.

The argument most commonly stated against surfacing rural roads, or even short sections of road, carrying low levels of traffic is usually based on construction cost. On this basis, surfacing is generally perceived as uneconomic. However, there is an argument to look a costs carefully, particularly the whole life cycle costs of having to re-gravel in a 3 to 8 year cycle using an ever diminishing resource. The increasing haul distances required to recover gravel, the destruction and loss of agricultural land after extraction and the use these ever diminishing non-renewable resources also has cost implications both for the environment and future development planning. Roads constructed with or on erodible materials and in areas where vehicle generated dust cause problems such as in villages and peri-urban centres are further areas where low cost sealing would lend itself to providing cost effective improvement.

Further examples of circumstances when provision of a sealed surface could provide a cost effective solution to engineering and environmental problems are given in Table 1. The social and political benefits of providing a surfaced road within a labour-based framework are also included in this table.

Although much more evidence is needed on the cost components of low-volume roads, life-cycle costing encourages a more flexible approach to road provision and greater scope for engineering innovation which can yield considerable cost savings. In the future, more low-volume roads are likely to be built, rehabilitated and maintained by labour-based methods. In this environment, the skill base of small contractors needs to be increased to include construction and maintenance of bituminous seals.

A range of products, construction technologies and maintenance techniques have been developed over the past decade or so which enable sealed roads to be provided at much lower costs and which greatly improve the economic benefits in life cycle terms. Thus, in some circumstances, sealed roads can provide economic benefits at relatively low traffic levels and spot improvements to short sections of roads can often give very large economic benefits indeed. Many of these techniques and technologies have been developed specifically with the small-scale contractors in mind. Maximum use is made of plant already available on many labour-based schemes which removes the need for the large capital intensive plant necessary for conventional surfacing schemes. The technology associated with labour-based methods of road construction continues to develop and the standard of construction is now generally much higher than in the past. Labour-based technology has also been developed for surfacing roads and has in some countries been used to construct roads carrying relatively large volumes of traffic.

4. CONVENTIONAL APPROACHES TO SURFACING

The most common method of sealing low-volume roads is to use a surface dressing. Surface dressing can provide an effective and economical running surface for newly constructed road pavements. It is a simple and durable road surface treatment which is highly effective if adequate care is taken in the planning and execution of the work. The process is used throughout the world both for surfacing medium and lightly-trafficked roads and as a maintenance operation for roads of all kinds.

Typically, the process is used for surfacing more lightly trafficked new roads carrying up to 500 vehicles/lane/day. In these circumstances, resealing with another surface dressing becomes necessary after 4-5 years but on more lightly trafficked roads these surfacings perform well for periods often in excess of 10 years.

The main function of a surface dressing is to provide a waterproof seal to a road surface. It will also arrest the deterioration of an existing road surface that is showing signs of distress, restore the skid resistance and provide a dust-free and durable running surface. Surface dressing is therefore a very important maintenance technique which is capable of greatly extending the life of existing sound road pavements. Under certain circumstances surface dressing may also significantly retard the rate of failure of a road pavement, postponing for a while the need for structural rehabilitation or reconstruction. Surface dressing has little or no structural strength itself but by preventing the ingress of water it enables the inherent strength of the pavement and the subgrade to be preserved.

A surface dressing comprises a thin film of 'binder', generally bitumen or tar, which is sprayed onto the road surface and then covered with a layer of stone chippings. The stone chippings protect this film of binder from damage by vehicle tyres, and they form a durable, skid-resistant and dust-free wearing surface.

Over the years various adaptations and improvements have been made to the "standard" double surface dressing method of construction which depends on the prevailing project circumstances. These include the use of triple seals, "inverted" surface dressings and "Cape seals". However, the conventional surfacing method for rural paved roads in many countries of southern Africa and elsewhere is to apply a double layer of surface dressing using a penetration grade or cut-back bituminous binder and aggregate on top of the primed road base. In some circumstances, the prime coat is also omitted. On very lightly trafficked roads, a single seal surfacing, utilising one layer of aggregate is also sometimes used. The most usual type of construction consists of a prime coat of cut-back bitumen, tar (in a few countries) or emulsion followed by a tack coat of bitumen and 13mm-19mm or 7mm-13mm stone and a seal coat of bitumen and 6mm-10mm or 1mm-6mm stone.

Table 1: Check List for Consideration of Labour-Based Sealing

Category	Sub-category	Considerations
Engineering	climate	heavy rainfall area; dry and dusty area
	terrain	flat, poorly drained; rolling and mountainous;
	geometry	alignment poor; steep gradients
	materials	lack of good materials in the area; plasticity too high resulting in slipperiness; poorly graded materials resulting in erosion;
	traffic	disproportionate amount of heavy traffic; even light traffic in poorly accessible areas
	spot improvements	not necessary to seal total length of road - look for worst spots
Financial	whole life costs	comparison of initial construction cost for sealed and unpaved options
	maintenance strategy	comparison of maintenance costs for sealed and unpaved options
Social and Political	employment	local employment with earnings spent in local area
	build local capacity	skills and broadening of work opportunities for local small-scale contractors
	improved access	all year access to schools and markets
Environmental and Health	dust	reduction in dust from gravels especially in villages and peri-urban areas
	erosion	heavy rainfall areas; erodible soils
	access to health services	all year access to hospitals and clinics especially in wet season when malaria and other illnesses are more prevalent
	food security	all year movement of food and agricultural inputs possible

5. ADAPTING TECHNOLOGIES TO LABOUR

5.1 Construction

In developed countries the technological development in road surfacing has been aimed at more sophisticated surfacing techniques to accommodate the very high level of traffic and the extremes of climatic conditions that prevail in many of these countries. Even in many African countries, contractors specialising in road surfacing have equipment designed for the rapid application of aggregate and binder. For the construction and maintenance of long sections of road there are large savings in the economy of scale in the use of this equipment where rapid application of the surfacing is important in terms of the efficient utilisation of plant and to minimise disruption to traffic. Even on low-volume and labour-based roads there may be circumstances where the use of plant is appropriate such as the surfacing of a previously constructed labour-based road or in peri-urban areas where the work is concentrated in a small area and the surfacing needs to be completed rapidly.

For many rural and labour-based road projects, however, where the rate of construction per kilometre is slower than for machine-based operations, the use of sophisticated plant for surfacing is neither appropriate nor cost-effective as utilisation rates are likely to be much lower. In these circumstances, surfacing can be completed equally well by labour-based methods using locally available resources.

5.2 Design

Most labour-based roads are between 3.5 metres and 5.5 metres wide. This range of widths is easily accommodated by labour-based surfacing methods. Even on wider roads, a first approach to upgrading to a bitumen surfaced standard is to provide a narrow-mat running surface with gravel shoulders, a technique used in a number of countries in the region and elsewhere. Roads surfaced to these standards are ideally suited to labour-based construction.

Although the provision of roads to this design has become less fashionable in recent years, the technique has proved to be extremely effective on lightly trafficked roads even in some countries in Europe. These roads are often built to lower standards of geometric design but road safety considerations can easily be accommodated by providing full width surfacing on tight curves or at the brow of hills where sight distances may be less than those recommended in a "standard" design approach. This "design by eye" approach has been successful even on feeder roads with relatively high levels of traffic where the main benefits are much lower construction costs through reduced earthworks.

When surfacing roads constructed by labour it is important to achieve as much compaction as possible to reduce secondary compaction by traffic and to produce a reasonable surface finish. A technique used on gravel roads destined for surfacing is to allow traffic compaction for a period before re-shaping and final rolling prior to surfacing. This technique is especially effective if roads are trafficked through one wet season although this is not always practicable.

Labour-based roads are usually constructed with a cross-fall of 8 per cent to assist the rapid dispersal of water from the running surface. On bitumen surfaced roads the cross-fall needs to be reduced to 2.5 to 3.0 per cent because the surface is impervious to water and the higher cross-fall causes construction problems due to binder run-off. The problem remains, however, on steep gradients where alternative solutions such as penetration macadam might be more appropriate, which are also suitable for construction by labour.

5.3 Equipment and Materials

One of the reasons that the bituminous sealing of roads is still regarded as an operation best done by plant and unsuited to labour-based works relates to the plant and materials necessary to carry out these works. The production of aggregate of nominally single size, with crushed faces in the quantities necessary for large scale works usually requires the use of a crushing plant and a large source of approved rock. Furthermore, the aggregate used for surfacing the highly trafficked roads must meet strict cleanness, hardness and durability specifications. The production of aggregate for low-volume roads whether in rural or peri-urban areas does not need to meet these stringent specifications if appropriate standards are developed. Traffic volumes are low and deterioration due to environmental factors is likely to be of more importance than traffic. Aggregate in sufficient quantities to match the speed of construction can be produced by labour without the use of large-scale equipment. The surfacing aggregate for rural road schemes constructed in Botswana during the 1980's was produced and applied using labour.

The binders commonly used for surfacing are penetration grade bitumens which require heating to high temperatures. These binders need a constant heat supply and for safety reasons are better suited to application with specialised equipment. Cut-back bitumen binders soften at lower temperatures but these are still well in excess of 100 degrees Celsius and are also not well suited to labour-based works. Nevertheless, these binders have been used in some countries for application by labour and one example of this is in Bangladesh.

Water-based emulsions which can be used at ambient temperatures or at temperatures much lower than straight run bitumen are more suitable for labour-based surfacing as they are easier to handle and safer to use. Emulsions "break" earlier in higher temperatures which reduces the tendency to run off although some reduction in cross-fall may also be necessary.

Very often, the simple adaptation of existing equipment is all that is required although the use of additional equipment such as hand lances allows a more controlled and even application of binder. On labour-based projects, pedestrian rollers are often available which can be used for the initial rolling of the seal before trafficking. Even without rollers, the use of any transport available for the initial compaction may be sufficient as traffic on many labour-based roads is low and travels at low speed which is ideal for compaction of the surfacing.

6. LABOUR-BASED SURFACING OPTIONS

There are a number of surfacing techniques which are amenable to application by labour. These include surface dressing (using emulsion), graded or OTTA seal, sand seals, slurry seal and penetration macadam.

6.1 Surface Dressing (emulsion)

The advantage of using a surface dressing is that the method is tried and tested and application rates of both binder and aggregate are well defined making the design fairly straightforward. Emulsion binders are much user-friendlier in that they do not need to be heated to such high temperature and some emulsions can be used at ambient temperatures. Some care is needed in the choice of emulsion to ensure that it is compatible with the aggregate used and that it has a "breaking" time appropriate to the method of construction. The surface dressing of very low volume roads is likely to be most applicable where suitable single sized aggregate is either readily available or easily won.

6.2 Graded Gravel Seal

The use of aggregate with a wide particle size distribution instead of the nominally single sized stone used in surface dressing was developed by the Norwegian Road Research Laboratory where it is known as an "OTTA" seal. Originally, the graded aggregate was crushed rock allowing a larger proportion of the crusher output to be used due to the wide particle size distribution allowed.

In graded gravel seals, crushed or uncrushed gravels with low aggregate strength are permitted and "soft" binders are normally recommended. The main differences between these seals and conventional seals are summarised qualitatively in Table 2.

TABLE 2: Qualitative Comparison of Graded Gravel Seal and Surface Dressing

Seal Type	Grading Envelope	Binder Hardness	Aggregate Strength
Graded seal	Wide	Soft	Strong or Weak
Conventional Seal	Narrow	Hard	Strong

6.2.1 Graded gravel seal design

An empirical approach is normally used for the design of graded gravel seals and considerable experience has already been acquired on the material properties and application rates of both the binder and aggregate constituents. The construction of these seals is far more forgiving, in terms of over-application of binder and aggregate, than a conventional seal. Bleeding can be more easily cured by blinding with sand because of the softer binder and the crushing effect caused by the over-application of aggregate is less of a problem with the more continuously graded aggregate. The use of a prime coat on the road base prior to sealing is optional.

The design guides shown in Table 3 and Table 4 are far more flexible in terms of binder content, aggregate particle size and application rates than for surface dressing. This flexibility is ideal for labour-based works where it is often impossible to effect strict control of application rates. On very low-volume roads, it is sufficient to sieve out the oversize and possibly the dust component without worrying too much about the grading.

This approach using local "sub-standard" aggregates was successfully demonstrated in the surfacing of a number of roads in Botswana in the early 1980's where aggregate was obtained by hand-screening sources of gravel from borrow pits. The technique has since been used to surface roads in a number of other countries including Kenya, Bangladesh and Zimbabwe.

TABLE 3: Typical design guidelines for OTTA seals in Botswana (Pinard 1995)

Type		Primed	Aggregates		Binder Spread Rate (l/m²)
			Fraction (mm)	Spread Rate (m3/m2)	
Single Seal		Yes	3(0)-12(16)	8-10	1.10-1.25
Double seal	First seal	No	12-19	8-10	1.25-1.40
	First seal	Yes	12-19		1.10-1.20
	Second seal	N/A	3-12		1.10-1.25

Table 4 Particle size distributions for Otta seals

Sieve type and size	Per cent passing sieve size for type of Otta seal	
BS sieve (mm)	Dense seal	Preferred for AADT<100
19	100	100
12.5	90-100	90-100
10	42-100	42-65
9.5	37-100	37-60
5	18-70	11-32
4.75	16-69	10-31
2.36	8-51	1-17
1.18	6-40	0-11
0.600	3-30	0-8
0.300	2-21	0-5
0.150	0-15	0-2
0.075	0-10	0-1

Evidence on the performance of these types of seal have shown them to have been satisfactory for over 12 years on roads carrying up to 300 vehicles per day. Occasional problems of poor surface/road base bonding can occur but this is likely to be more acute with fine-grained road base materials and priming is recommended in these circumstances.

Generally, the durability of a bituminous surfacing is determined by the effects of ageing and embrittlement of the bitumen. Even the coarse graded gravel seals are generally less open textured and are thicker than an equivalent conventional surface dressing and for these reasons, graded gravel seals might prove to be more durable.

Some of the suggested merits of graded seals for lightly trafficked roads are given in Table 5.

Table 5: Relative Merits of Graded and Conventional Seals

	Graded gravel seal	Conventional seal
Use of materials	• Relaxed aggregate specifications • Maximum use of crusher output	• Stringent aggregate specifications • Minimum use of crusher output
Design	• Empirical approach • Relies on site trials	• Rational approach
Construction	• Binder and aggregate application rates not critical	• Binder and aggregate application rates applied strictly
Durability	• Durability aided by the use of soft binders	• Durability reduced by the use of hard binders

6.3 Sand Seal

Where chippings for a surface dressing are unobtainable or are very costly to provide, sand can be used as 'cover material' for a seal. Sand seals are less durable under heavy traffic than surface dressings but can provide a satisfactory surfacing for lightly trafficked roads carrying less than 100 vehicles per lane per day.

Sand is often available in areas where aggregates for the production of surfacing stone are scarce. These areas include arid areas, rivers and alluvial plains. In desert areas dune sand is often available and although these sands are not as durable as the river deposits they can, nevertheless be used for lightly trafficked roads. In low lying and alluvial areas quartz rich sand is often available in river beds and surfacing seals constructed using these sands can perform extremely well.

Conventionally, sand seals are applied by a single application of bitumen by a distributor followed immediately by an application of sand size material. It is not possible, however, to design a sand seal as precisely as is possible for, say, a surface dressing although typical recommendations would be that clean coarse sand should be used, with a maximum size of 6mm, containing no more than 15 percent of material finer than 0.3mm and a maximum of 2 percent of material finer than 0.1mm. The sand should be applied at a rate of 6 to 7 x 10-3 m^3/m^2 (NITRR 1971) and the binder, which may be a cutback or an emulsion, should be spread at a rate of approximately 1.0 to 1.2 kg/m^2 depending on the type of surface being sealed.

Because sand seals can be constructed with emulsion as the binder, they are well-suited to construction by labour-based methods and it is often sufficient just to hand-screen out any over-sized particles. Some over application of the sand can be tolerated.

6.4 Slurry Seal

In this process a fine, graded, aggregate is mixed at ambient temperature with a bitumen emulsion with a relatively high bitumen content. Some cement is usually added (Hawken 1967) and he mixture is applied to the road surface as a free-flowing slurry in a layer 5mm to 10mm thick. The slurry penetrates and seals surface voids and cracks very effectively, thus the process is particularly well suited to the maintenance of old bitumen surfaces. When the emulsion 'breaks' an impermeable bitumen-rich surface results. The aggregates used in slurry seals are normally not greater than 6mm in size but some specifications include material up to 10mm in size.

Slurry seals can be made with simple, slow breaking, (stable) anionic emulsions in a static mixing plant and then spread on the road by hand or by simple drag spreaders. When spread the slurry needs little, if any, compaction and traffic compaction alone will often suffice once the emulsion has 'broken'.

6.5 Penetration Macadam

The two types of bituminous penetration macadam are semi-grouted and full depth (The Asphalt Institute, 1964). The type of macadam selected will depend on the prevailing site conditions and the materials available.

6.5.1 Semi-grouted macadam.

Construction of 50mm thick semi-grouted macadam involves the following steps:

(i) Placing a layer of sand or quarry fines on the prepared formation to a depth of not more than 13mm (½ inch).

(ii) A uniform mixture of specified proportions of 40mm and 28mm single sized aggregates and14 to 20mm aggregate is placed on the sand layer to give a thickness of 50mm after compaction. The aggregate is placed in such a way as to prevent segregation and to give as dense a layer as possible.

(iii) During rolling a minimum amount of water is added to bring up an evenly distributed slurry of the fines to depth of not more than two-thirds of the thickness of the layer. Compaction is continued until appreciable movement of the aggregate under the roller ceases.

(iv) K1-60 or K1-70 emulsion is then applied at a rate of between 3 and 5.5 litres per square metre.

(v) Immediately after the emulsion has been applied sufficient 6 to 10mm size chippings are spread to fill up any interstices and then rolled in.

6.5.2 Full-depth grouting.

This type of construction is essentially the same as semi-grouted macadam except that the layer of fines is omitted. A heavier application of emulsion is required to ensure that asphalt reaches to the full depth of the aggregate layer. Typical application rates for emulsion are between 5.5 and 7 litres per square metre.

Pedestrian type vibrating rollers are required for penetration macadam to ensure that the fine materials fill the interstices between the hand pitched stones.

6.6 Concrete Strip

Traffickability is often a problem on steep rocky sections of low-volume unsealed roads. The cost of the provision of a sufficiently thick layer of earth and gravel to provide a reasonably smooth running surface is often prohibitive and is further exacerbated by erosion of the gravel layer. An appropriate solution in these circumstances might be use concrete strips in the wheel

paths with occasional passing places (which may be gravelled). These sections can be constructed by labour, as quite simple formwork is required for the strips.

7. CONCLUSIONS

Knowledge and application of appropriate sealing technologies enhances the skill base and opportunities for small scale contractors who traditionally only have capacity to construct and maintain unpaved roads.

Standard surfacing technologies have been successfully adapted to labour-based road construction and maintenance works in a number of countries. Design options available to the labour-based practitioner include the use of graded or OTTA seals, sand and slurry seals and penetration macadam.

The production and screening of aggregates as well as the application of binder and stone do not require the use of expensive plant and equipment on labour-based works where economies of scale are not a constraint.
The use of bituminous emulsions enables binders to be easily and safely handled.

Labour-based sealing has been considered in this paper mainly as a spot improvement option where engineering conditions necessitate the need for an alternative surfacing to earth or gravel to ensure access.

In some circumstances, the provision of a bituminous surfacing on longer lengths of low volume and labour-based roads may also be justified in life cycle terms by the adoption of appropriate standards and technologies and if the social, economic and environmental benefits, in addition to the usual road user benefits, can be quantified.

8. REFERENCES

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