COLD IN PLACE RECYCLING: A RELEVANT PROCESS FOR ROAD REHABILITATION AND UPGRADING

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Abstract

The cold in place recycling process is gaining recognition and popularity world-wide as a cost-effective means of rehabilitating distressed road pavements. The process requires the use of specially designed recycling machines. The heart of these machines is a large milling drum fitted with tungsten-tipped steel teeth that makes it possible to recycle pavements that include thick asphalt layers.

Stabilising agents, such as cement slurry, bitumen emulsion and foamed bitumen, can be injected directly into the recycler's mixing chamber while the milling operation is being carried out, ensuring excellent mixing of the stabilising agent with the milled material. The process is carried out in a single-pass operation, enabling a high rate of production to be achieved.

One of the main benefits of the cold in place recycling process is that the material in the existing distressed road pavement is similtaneously recycled and mixed with the stabilising agent, enabling the road pavement to be strengthened without the need to import expensive aggregate. Other benefits include a short construction period as well as significant improvements to traffic safety. These advantages add up to significantly lower unit costs for road rehabilitation, compared to other methods.

This paper explains the cold in place recycling process and examines its benefits compared to other methods of rehabilitating and upgrading road pavements. Also covered are the engineering properties that can be expected when road building materials are treated with the various stabilising agents. Recommendations are given for the choice of the most cost-effective stabilising agent depending upon a number of variables.

1. INTRODUCTION

For centuries man has relied heavily on roads in one form or another as the primary means of communication and transport. The development of motorised transport has had a huge impact on the need to provide appropriate road networks. Inevitably these roads reach the end of their structural lives. They become cracked, potholed, and bumpy, attracting public outcry for speedy repair and, in many countries, road authorities are now placing far more emphasis on maintenance and rehabilitation than on the development of new roads.

Until fairly recently the rehabilitation of road pavements has taken the form of re-construction using plant and methods conventionally employed for the construction of new roads. Although adequate, the procedure is clumsy, particularly when working under traffic, and relatively inefficient as it is difficult to make full use of the in situ materials in the pavement.

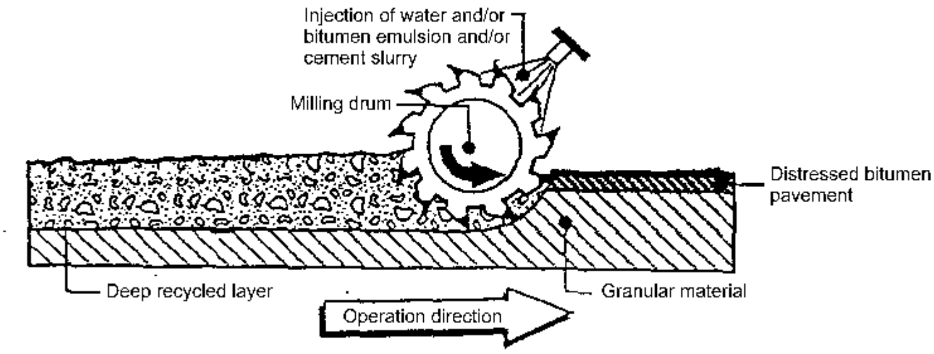
Increasing environmental and economic pressures have forced engineers to consider reusing the materials in existing distressed pavements, rather than to open up new quarries and import material to reconstruct the road pavement. The modern trend in rehabilitation design is to utilise the intrinsic values of the material within the existing pavement. Cold in place recycling consists essentially of milling the existing road pavement to a predetermined depth in order to recover the material that was used in the original construction. This material is then reprocessed, normally with a stabilising agent, to form a new strengthened pavement layer.

The process evolved during the late 1980's along with the development of large recyclers. Technologically sophisticated machines are now available that have the ability to recycle the material in the upper layers of existing distressed road pavements to depths in excess of 300mm in a single pass.

Cold in place recycling is now an accepted road rehabilitation process in many countries of the world. This process can be used to upgrade and rehabilitate a wide variety of road pavements, ranging from lightly trafficked unsurfaced roads to highways carrying the heaviest traffic.

2. THE COLD IN PLACE RECYCLING PROCESS

Cold deep in place recycling is carried out using specialised recycling machines, the heart of which is a milling drum equipped with a large number of hardened steel picks. The drum rotates upwards, milling the material in the existing road, as shown diagramatically below.



As the milling process is taking place water from a water tanker that is pushed ahead of the recycler is delivered through a flexible hose and is sprayed into the mixing chamber. The water, which is metered accurately by the microprocessor controlled pumping system, is mixed thoroughly together with the milled material to bring it up to its optimum compaction moisture content.

3. RECYCLING WITH STABILISING AGENTS

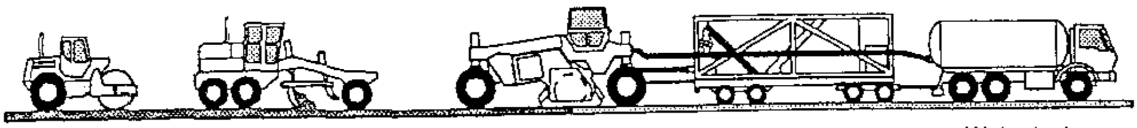
3.1 Recycling with cement

Typically between 2% and 4% (by mass) of cement is added during the recycling process when this stabilising agent is used. The cement may be added in three different ways:

- spread onto the surface of the road ahead of the recycler. In a single operation, the recycler passes over the spread cement, mixing it together with the underlying material;
- mixed together with water in a specially designed slurry mixer to form a slurry that is then introduced directly into the mixing chamber. This ensures accurate application rates and eliminates the wastage of cement, (it cannot blow away in the wind); or
- applied using a specialised cement spreader incorporated in the recycler's frame.

Behind the recycling machine the recycled layer of material is profiled with a motor grader before being compacted using a vibratory roller. Finally, a rubber tyred roller is normally used to obtain a well-knitted surface finish.

Once compaction of the recycled layer has been completed, the road should be surfaced with a bituminous layer. This may vary, depending upon the traffic loading, from a thin surface treatment in the case of lightly trafficked roads, to one or more layers of hot-mixed asphalt when the pavement carries heavy traffic.



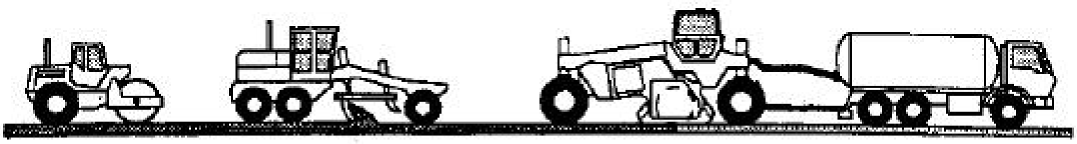
The recycling train is depicted in the diagram above.

3.2 Recycling with bitumen emulsion

Bitumen emulsion is manufactured by emulsifying bitumen and water, using emulsifying agents. Usually the emulsion contains approximately 60% of bitumen and 40% of water. The advantage of bitumen emulsion is that it is a liquid at ambient temperatures and can be mixed with road-building aggregates without the need to heat the stone and the bitumen, as is the case with hot-mixed asphalt.

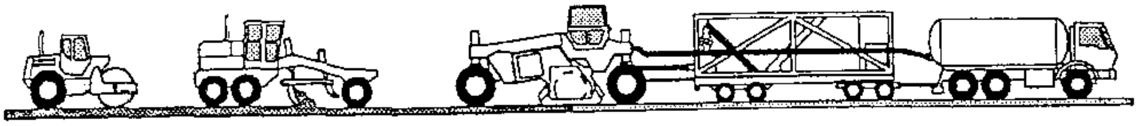
When bitumen emulsion is used in the cold in place recycling process, it is transported in a tanker that is pushed ahead of the recycling machine, as shown in the diagram below. The emulsion is delivered to the recycling machine via a flexible hose and sprayed into the mixing chamber of the recycler as it moves forward. The milled material and the bitumen emulsion are thoroughly mixed together in the recycler's mixing chamber before being discharged from the rear of the recycler and profiled using a motor grader. The new layer is then compacted in the same way as the cement treated layer.

Typically around 5% (by mass) of bitumen emulsion is added to granular road building materials. However if the existing pavement consists of a thick layer of asphalt, the amount of emulsion can be reduced to between 3% and 4%, depending upon the proportion of asphalt in the mix.



A typical recycling train where bitumen emulsion is being used is shown above.

In many cases a combination of bitumen emulsion and cement is found to be effective. The percentage of cement that is added depends on the design approach used and may typically vary from 1% to 3%. It is introduced into the recycled mixture together with the bitumen emulsion using any of the methods described above.



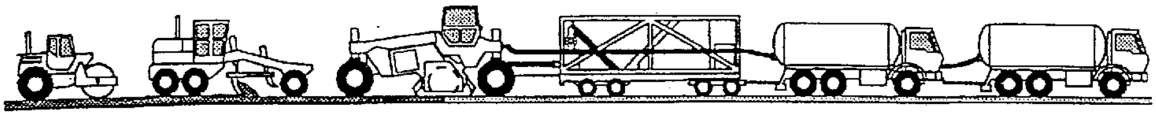
The configuration of the recycling train where cement is used together with bitumen emulsion is shown in the diagram above.

Advantages of using a combination of cement and bitumen emulsion are:
- improved adhesion of the bitumen to the aggregate;
- more rapid gain in strength, enabling the road to be opened to traffic quicker; and
- improved ultimate strength of the recycled layer.

3.3 Recycling with foamed bitumen

Foamed bitumen is manufactured onboard the recycling machine using a specialised process that adds a small percentage of water to hot penetration-grade bitumen. The foamed bitumen is sprayed directly into the mixing chamber of the recycling machine in the same way as the bitumen emulsion. The foaming process enables normal grades of bitumen to be mixed with cold, moist recycled material without first having to be emulsified. In the case of granular materials, between 3% and 5% of foamed bitumen (by mass) is normally added. When the recycled material contains a high proportion of asphalt, a reduced content of foamed bitumen of between 2% to 3% is common.

As in the case of bitumen emulsion, there are benefits in adding small percentages (typically 1% to 2%) of cement, together with the foamed bitumen. As described above for bitumen emulsion, the cement can be added either as a powder, or as a cement/water slurry using a specialised slurry mixer.



A typical configuration of a recycling train using foamed bitumen with cement is shown above.

4. ADVANTAGES OF COLD DEEP IN PLACE RECYCLING

The main advantages of cold in place recycling are:

- **Consistent mixing.** Excellent mixing of in situ materials with new aggregate and/or stabilising agents is assured. Addition of water and fluid stabilising agents is electronically controlled and sprayed across the full width of the milling drum through a series of nozzles;
- **Precise control of layer thickness.** Once set, the depth of cut of the milling drum is controlled with sensors, ensuring accurate control of layer thickness;
- **Shorter construction period.** This is due to the high production rate of modern recycling machines;
- **Less reliance on fine weather conditions.** The process offers the distinct advantage of being able to continue working during periods of uncertain weather. When rain threatens the work can be temporarily stopped and then restarted again as soon as the rain has passed; and
- **Greatly reduced traffic disruption and improved safety.** The entire process can be carried out on one half of the road width, leaving the other half open to traffic

5. APPLICATIONS OF COLD IN PLACE RECYCLING

A wide variety of applications of the cold in place recycling process is possible. In broad terms, road pavements can be recycled to depths of as little as 100mm, up to depths in excess of 300mm. Three typical variations are given below, but the process is by no means limited to these specific applications.

5.1 Upgrading of unsurfaced roads

Unsurfaced roads cause problems during the dry season when vehicles moving along them cause clouds of dust during the dry season, while in the wet season they become unpleasantly muddy, and dangerously slippery. Maintenance of the gravel wearing course is on-going, with regular grading being required to maintain the roads' riding quality.

From time to time it is necessary to replenish the gravel wearing course, using borrowpits located along the routes. Besides the cost of the excavating, loading, hauling and placing the gravel on a regular basis, there is an adverse impact on the environment, as with time the borrowpits grow bigger and bigger, becoming eyesores and causing soil erosion.

The cold in place recycling process offers an economical means of upgrading these roads. By strengthening them using this process, and providing them with a durable blacktopped surface, the dust and mud problems are eliminated. Besides this, studies carried out in many countries show that economic benefits can be expected in the longer term, due to a substantial reduction in maintenance costs.

The upgrading of unsurfaced, lightly trafficked rural and village roads can be carried out very cost-effectively by recycling 10cm to 12cm of the existing gravel wearing course with either bitumen emulsion or foamed bitumen, and then applying a thin surface treatment such as a chip seal or bituminous slurry seal.

5.2 Recycling thin asphalt pavement layers

Pavements where the distress is caused by aging of the asphalt layers can be effectively rehabilitated by recycling a relatively thin layer. This type of distress can be identified by cracking and surface degradation that occurs without severe rutting.

The minimum depth of this type of recycling is usually around 80mm and the recycling is carried out with the addition of bitumen emulsion, followed by the application of a hot-mix asphalt surfacing.

In order to improve the gradation of the milled asphalt, so as to ensure good compaction, it is often necessary to spread a layer of crusher dust onto the surface of the existing pavement prior to recycling so that it mixes with the asphalt during the recycling process.

5.3 Structural strengthening by deep recycling

Modern recycling machines are capable of recycling tough pavements consisting of thick layers of hot-mixed asphalt. The complete process is normally carried out in a single pass, significantly cutting construction time and reducing traffic congestion. Very little new material, if any, has to be brought in; the process recycles and strengthens the material in the pavement of the existing road in a single operation.
The thick layer that can be recycled using modern recycling machines means that it is possible not only to rectify superficial asphalt aging problems described above, but is also to be able to address weaknesses that occur deeper in the pavement. These can normally be identified by the presence of severe deformation and rutting, which occur together with cracking and potholing.

Recycled layer thicknesses in excess of 300mm, using cement alone, or combinations of cement and bitumen emulsion or foamed bitumen, are commonplace. Obviously the use of heavy vibratory rollers is essential to ensure proper compaction of thick recycled layers. Vibratory rollers with a static mass of at least 17 tons are recommended when thick layers are recycled. The roller should be equipped with variable amplitude and frequency control; initial passes should be carried out with a high amplitude/low frequency setting while final compaction should be achieved by carrying out further passes with a high frequency/low amplitude setting.
In the case of very heavily trafficked roads it is normally necessary to strength the pavement further by paving one or more layers of hot-mixed asphalt on top of the recycled layer.

6. CHOICE OF STABILISING AGENTS

The principal reasons for the treatment of recycled materials with stabilising agents are:

- To improve strength and hence the structural capacity of the pavement without the need to import additional material to increase pavement thickness;

- To enhance durability so as to ensure the long-term performance of the pavement; and
- To improve resistance to moisture.

The choice of the most effective stabilising agent for a particular application depends on several factors, the principals of which are:

- Price. The relative costs of the stabilising agent;
- Availability. The ease with which the stabilising agent can be resourced;
- Acceptability. Certain stabilising agents are often more acceptable locally. The local experience that has been gained with a particular product often has a large influence as regards its acceptability; and
- Material type. Different stabilising agents are more effective with certain types of aggregate than others.

In the following tables the advantages and disadvantages of the various stabilising agents covered previously in this paper are compared:

6.1 CEMENT

ADVANTAGES	DISADVANTAGES
Easy to apply as a powder or slurry. Normally less expensive than bitumen or emulsion. Improves material's resistance to moisture.	Shrinkage cracking can be a problem. Cracking can, however, be substantially reduced by careful mix design – keeping cement content as low as possible and keeping the moisture content on the low side.

6.2 BITUMEN EMULSION

ADVANTAGES	DISADVANTAGES
Easy to apply - the emulsion is sprayed directly into the recycler's mixing chamber. Emulsion treatment produces a flexible, fatigue resistant layer that is not prone to cracking. Once fully cured, emulsion treated material is resistant to the ingress of moisture.	Usually more expensive than cement or foamed bitumen. Emulsion must be formulated to be compatible with the recycled material, with a suitable "break" time to enable proper mixing and compaction. Emulsion treatment can be a problem when in situ moisture contents are high – the addition of the emulsion will push the moisture content well above optimum resulting in heaving of the recycled layer.

6.3 COMBINATION OF BITUMEN EMULSION AND CEMENT

ADVANTAGES	DISADVANTAGES
The cement can be injected as a slurry together with the emulsion into the recycler's mixing chamber. Alternatively it can be applied as a powder, and the emulsion sprayed by itself into the mixing chamber. The cement/emulsion combination produces higher strengths, cures quicker, and is more resistant to water than emulsion alone. If properly designed it is not prone to shrinkage cracking.	More expensive than either cement or emulsion alone. Also more expensive than foamed bitumen. The emulsion must be formulated to have a suitable "break" time when it is mixed together with the recycled material and the cement. Premature breaking of the emulsion when it comes into contact with the cement will cause problems with unsatisfactory mixing and "balling" - correct formulation of the emulsion is essential.

6.4 FOAMED BITUMEN

ADVANTAGES	DISADVANTAGES
Easy application - the foamed bitumen is sprayed directly into the recycler's mixing chamber. Foamed bitumen treated material forms a flexible layer with good fatigue properties that is not prone to shrinkage cracking. It is resistant to the ingress of water. Usually less expensive than bitumen emulsion or a combination of emulsion and cement. Additional water is not added to the recycled material, as is the case when emulsion is used. Rapid strength gain - the road can be trafficked immediately after compaction is complete.	Requires a supply of hot (180^{o}C) bitumen. For foamed bitumen treatment, the material should have between 5% and 15% passing the 75 micron sieve size. If this is not the case, the grading should be rectified by importing and spreading a layer of suitably graded aggregate over the layer to be recycled.

6.5 FOAMED BITUMEN AND CEMENT

ADVANTAGES	DISADVANTAGES
When a low percentage of cement (1% to 2%) is used in combination with foamed bitumen, it improves the strength of the recycled material significantly. In addition, material treated with this combination will have an even higher resistance to water compared to foamed bitumen alone. Less expensive than a combination of bitumen emulsion and cement.	It has the same bitumen temperature and aggregate grading requirements as foamed bitumen. It is more expensive than foamed bitumen alone.

7. TYPICAL PROPERTIES OF STABILISED MATERIALS

Typical properties of the materials treated with the five varieties/combinations of stabilising agents discussed in the previous tables are summarised in the table below. These properties are based on tests carried out on well-graded crushed aggregates. It will be noted that some tests are not applicable to all stabiliser types, for instance unconfined compressive strength testing is not considered applicable for evaluating bituminously treated materials.

Except in the case of cement stabilised materials, these properties are based on tests carried out on Marshall specimens compacted by applying 75 blows of a standard Marshall hammer per face. Specimens are cured by leaving the samples in their moulds for 24 hours at ambient temperature before extracting and then curing them in a forced draft oven for 72 hours at 60^{o}C. All testing is carried out at a temperature of 25^{o}C.

The unconfined compressive strength and indirect tensile strength testing for cement stabilised materials is carried out on cylindrical specimens (150mm diameter x 125mm length), compacted to 100% Mod. AASHTO density, and damp cured at an elevated temperature of 70^{o}C to 75^{o}C for 24 hours.

TEST PARAMETER	CEMENT (3%)	BITUMEN EMULSION (3.5% net bitumen)	EMULSION/ CEMENT (3.5% net bitumen plus 2% cement)	FOAMED BITUMEN (3.5%)	FOAMED BITUMEN/ CEMENT (3.5% bitumen plus 1% cement)
Unconfined Compressive Strength (MPa)	3	n/a	n/a	n/a	n/a
Indirect Tensile Strength (Dry) kPa	250	200	500	200	500
Indirect Tensile Strength (Soaked) kPa	n/a	80	250	80	300
Marshall Stability (Dry) kN	n/a	10	20	10	20
Marshall Stability (Soaked) kN	5 000	1 500	3 500	2 500	3 500
Resilient Modulus (Dry) Mpa	5 000	2 000	3 500	2 000	3 500

The choice of the most suitable stabilising agent will therefore ultimately depend on:

- consideration of the principal factors listed in paragraph 6 above;
- their respective advantages and disadvantages; and
- the engineering properties that can be achieved by stabilising the material with the particular stabilising agent

8. INFLUENCE OF STABILISING AGENTS ON PAVEMENT LAYER THICKNESS

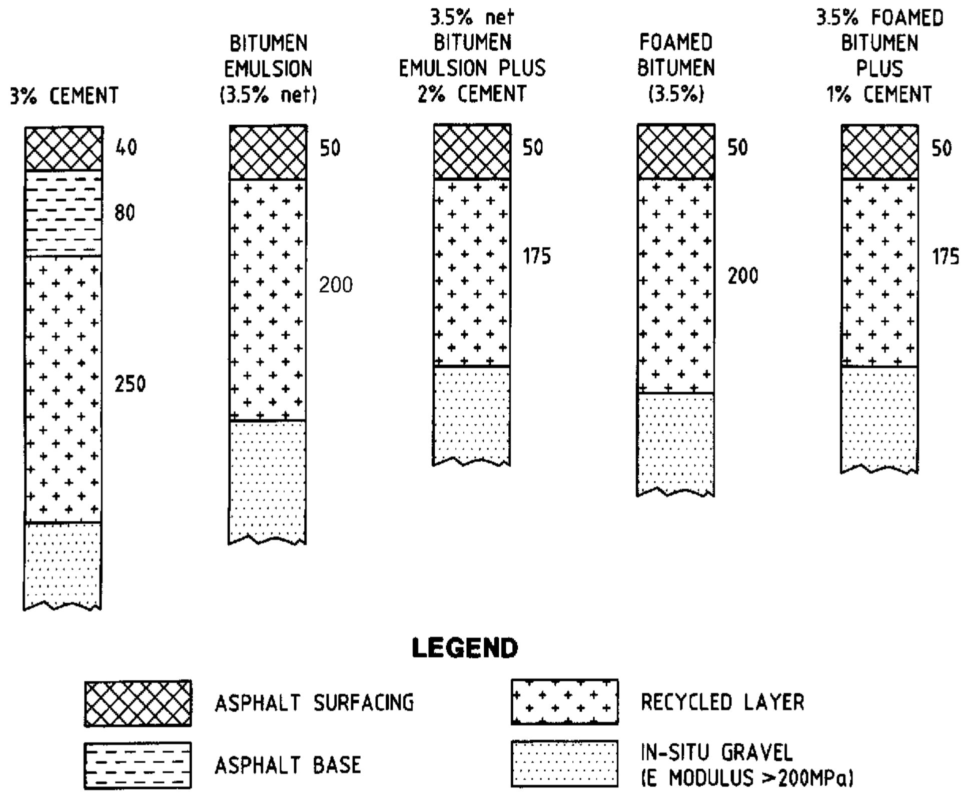
Illustrated below are examples of various options of pavement designs using a recycled layer that has been treated with each of the stabilising agents and combinations discussed above. These pavements are modelled to have similar structural capacities. A linear elastic programme (ELSYM5) was used, together with the methodology and transfer functions recommended in the South African Mechanistic Design Method.

The typical stiffness values shown in the table above, together with Poisson's Ratios of .35 for granular unbound and cementitiously bound layers, and .44 for bituminously bound layers were use in this analysis. Due to insufficient information on the fatigue properties of emulsion and foamed bitumen treated materials, the transfer functions for hot-mixed asphalt bases were used, and the thickness of these layers was increased using a factor of 1.5.

While perhaps not completely accurate, this analysis illustrates the effect that different stabilising agents have in requiring different layer thicknesses in order to carry the same design traffic, depending on the engineering properties, such as stiffness and fatigue, of the stabilised recycled layer.

For instance, in this example, it can be seen that the cement stabilised pavement requires a thicker recycled layer as well as an asphalt base layer compared to the foamed bitumen treated pavement, where a thinner recycled layer without an asphalt base is shown to be adequate.

COMPARISON OF PAVEMENT DESIGNS USING VARIOUS STABILISING AGENTS



The choice of stabilising agent has a significant impact on the pavement cost, as the stabilising agent itself is normally the largest component in the total recycling cost. In order to evaluate the most cost-effective design for a particular project it is therefore necessary to carry out pavement designs using each of the stabilising agents. Cost comparisons can then be made based on the thickness of the layers required using local rates for the various stabilising agents.

It must be borne in mind that in the above example a uniform stiffness was assumed for the material under the recycled layer. In practise this is very seldom, if ever, the case, and it is obviously essential to carry out investigations to assess the quality of the materials within, as well as below the depth of recycled layer. In this way the variability of materials' qualities can be taken into account when finalising the pavement design.

9. CONCLUSIONS

The development of powerful, efficient, recycling machines has made it possible for a variety of pavement recycling applications to be considered, ranging from unsurfaced, lightly trafficked rural roads to busy highways and city streets.

The process allows a wide selection of stabilising agents to be employed to strengthen the pavement without having to import additional material to thicken it, as well as to enhance durability and improve its resistance to moisture

Cost savings in excess of 20% are normally achieved, compared to the use of other more conventional methods for rehabilitating and upgrading roads. There is no doubt that the rapid growth of cold in place recycling throughout the world is evidence of the cost-effectiveness of this process.