

Cold In-Place Recycling: An Introduction

By: *Engr. Ahmad Kamil bin Arshad, M.I.E.M., P.Eng.*

1.0 INTRODUCTION

Cold in-place recycling (CIPR) is defined as a pavement rehabilitation technique in which the existing pavement materials are reused in-place as base layer. The materials are mixed in-place without the application of heat. Stabilising agents such as cement, lime, bitumen emulsion or foamed bitumen are added and mixed with the materials to provide additional strength to the pavement. The recycled material is then compacted and a wearing course is laid on top of the completed base course to provide a smooth riding surface.

CIPR can be used to eliminate a variety of pavement distresses such as rutting, cracking, surface irregularities and base problems. The process can be carried out with a single machine or an equipment train consisting of different machines. CIPR is an alternative method to the more traditional methods of structural overlay or reconstruction, whereby existing pavement distresses are addressed and additional strength required for future traffic increase is provided for, by using a stabilising agent to increase the load carrying properties of the recycled pavement base.

CIPR can be performed in two ways: in partial-depth recycling, 50-100 mm of the asphalt layer is used to produce a base course. In full depth recycling, also known as full depth reclamation, both asphalt and portions of unbound aggregate layers are crushed, mixed with binder, and placed as a stabilised base course. However, the Asphalt Recycling and Reclaiming Association (ARRA) defines cold in-place recycling as partial depth recycling of the existing pavement while the full depth recycling is defined as full depth reclamation [1].

This article attempts to provide a brief introduction to the CIPR process, equipment for the process, selection criteria for the suitable pavement candidate, mix design, construction process, quality control and finally, the



Figure 1: CIPR equipment train using foamed bitumen

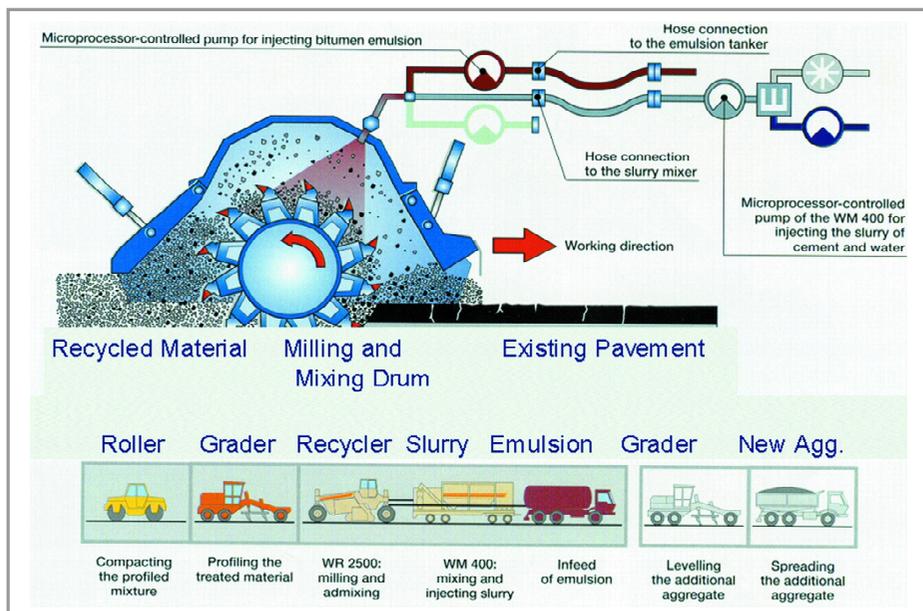


Figure 2: Schematic diagram of the cold in-place recycling process [4]

advantages and disadvantages of this method. The construction process to be explained is confined to the single pass equipment train. This article focuses on full depth reclamation rather than partial depth recycling.

2.0 EQUIPMENT

CIPR requires a set of equipment consisting of a recycling machine, a bitumen tanker and a water tanker (for foamed bitumen), apart from a motor

grader and a roller (Figure 1). The configuration is dependant on what type of stabilising agent is to be used. The set of equipment is normally linked together like a train by means of push bars or drawbars, with the recycling machine acting as the locomotive, driving the whole set of equipment. Hoses connect the bitumen, water and/or cement slurry from each of the tankers to the mixing chamber of the recycling machine.

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3.0 COLD IN-PLACE RECYCLING PROCESS

Recycling machines equipped with a milling/mixing drum, mills the material in the existing road pavement. Water, sprayed into the mixing chamber, is mixed thoroughly together with the material to achieve optimum compaction moisture content (Figure 2).

Stabilising agents such as cement and bitumen emulsion (in fluid form) are also introduced in a similar manner. However, foamed bitumen is injected into the mixing chamber through a separate spraybar. Stabilising agents such as cement, which are in powdered form, are normally spread onto the existing road surface ahead of the recycler. The recycler passes over the cement powder, mixing it, together with water, into the underlying material in a single operation.

After the recycling, an initial roller pass is given to the material to consolidate it before the surface is profiled by a motor grader. The material is then compacted using a vibratory roller to obtain the required density. Curing time is required for material stabilised with cement or bitumen emulsion to obtain the required strength before the road is opened to traffic. After curing, a layer of surface course (binder and wearing) is laid above the recycled layer to give the pavement a smooth riding quality.

4.0 SELECTION CRITERIA OF PAVEMENT CANDIDATE

Pavement evaluation is carried out on the existing pavement to determine its condition. This normally comprises of traffic survey, surface condition survey, deflection measurement using FWD, DCP tests to determine the strength of the base, sub-base and subgrade layers, sampling from trial pits and various laboratory tests (such as asphalt content, existing gradation, Atterberg limits and moisture content of the reclaimed asphalt and base aggregate).

If the pavement exhibits load-related distress (such as alligator cracking and rutting over a threshold level) and a structural evaluation of the pavement indicates that the existing structure is inadequate for the present and future

traffic, the existing pavement requires strengthening.

The traditional rehabilitation method is to place a new overlay over the deteriorated pavement but this does not address most of the underlying pavement defects and reflective cracking will appear after a certain time. If the base has deteriorated, partial reconstruction may be required to rehabilitate the pavement. An alternative to the above is CIPR and the method is suitable for the following cases [2]:

- 1) to upgrade the structural capacity of the roadway without substantially altering the horizontal and vertical geometry.
- 2) to correct all surface distresses (such as rutting, cracks and potholes) and mixture problems in the asphaltic concrete.
- 3) to correct base course deficiencies such as gradation, moisture problem and density.

However, CIPR does not correct pavement with subgrade related distresses. In this case, the existing pavement structure must be disturbed to improve the subgrade first by other methods. CIPR is also not recommended for pavement with subgrade CBR value of less than 3 percent unless the subgrade is improved or adequate depth of cover is provided for the subgrade [6]. This is because it is difficult to compact the recycled material effectively on poor subgrade support.



Figure 3: A pavement candidate for CIPR (full depth reclamation) Among the distresses identified include deep cracking, reflective cracking, pothole, rutting/shoving and insufficient base strength

5.0 MIX DESIGN

The objectives of mix design for CIPR are as follows:

- 1) to establish the grading of the material to be recycled and its variability after pulverisation, so that

the influences of grading on the mix properties can be determined;

- 2) to find the optimum moisture content compatible with compaction by rolling in the field;
- 3) to find the amount of stabilising agent required (cement or bituminous binder) at the optimum moisture content to obtain the required strength.

Mix design procedure should provide a balanced design that safeguards against the failure modes of a pavement (shear, permanent deformation and fatigue failure) and should incorporate tests aimed at measuring the appropriate strength parameters for all the failure modes.

Mix design process using cement as the stabilising agent involves the following steps:

1. Preparation of specimens for testing (five nos. 7kg batches).
2. Determination of hygroscopic moisture content (two nos. samples from remaining material above).
3. Determination of Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of stabilised material (AASHTO T180 test).
4. Preparation of specimens for Unconfined Compressive Strength (UCS) Test (at different cement content, 2% apart).
5. Curing of Specimen (7 days at temperature of 22 – 25 °C in suitable curing room. After 7 days, submerge in water for 4 hours at 22 – 25 °C.
6. Testing to determine the UCS value (specimens tested to failure at loading rate of 140 kPa/s).
7. Selection of the required cement content to achieve specified value. (For each cement content, average UCS of three specimens is taken and a graph of cement content vs. strength is plotted. The required cement content is determined from the plot.)

For foamed bitumen, the mix design process is as follows:

1. Determination of the optimum foaming characteristics of bitumen to be used.
2. Preparation of aggregate for treatment with foamed bitumen (five nos. 10kg batches).

3. Determination of optimum binder content for the prepared aggregates (at different binder content, 1% apart).
 - Sample preparation and treatment with foamed bitumen.
 - Preparation of Briquettes (using Marshall mould with 75 hammer blows on each face).
 - Curing (24 hours in mould at room temperature and 72 hours at 40°C).
 - Calculation of dry density of compacted specimens.
 - Determination of Indirect Tensile Strength (ITS) value.
 - Determination of Design Bitumen Content (bitumen content at maximum value of soaked ITS).
4. Other material properties such as Resilient Modulus and Dynamic Creep, if required, are also determined.

Detailed explanation of the mix design process (including mix design using bitumen emulsion as stabilising agent) can be found in publications as listed in the Bibliography section.

5.1 STABILISING AGENTS

The aim of a stabilising agent is to bind the individual particles together to increase strength and/or to make the material more water resistant. The most popular stabilising agents are cementitious and bituminous stabilising agents. Figure 4 provides a flow chart for the guide on the selection of suitable stabilising agent for CIPR [3].

5.1.1 CEMENTITIOUS STABILISING AGENTS

Cement is the most commonly used stabilising agent because of its availability and acceptance as construction material. However, cement-treated material is prone to cracking and must be controlled to prevent detrimental effects. There are two types of cracking in cement treated material – shrinkage cracking caused by the hydration of cement and traffic induced cracks. Shrinkage cracking is controlled by curing for at least 7 days by regularly spraying the surface with water or using a curing membrane such as a temporary seal or asphalt layer. To allow for traffic induced

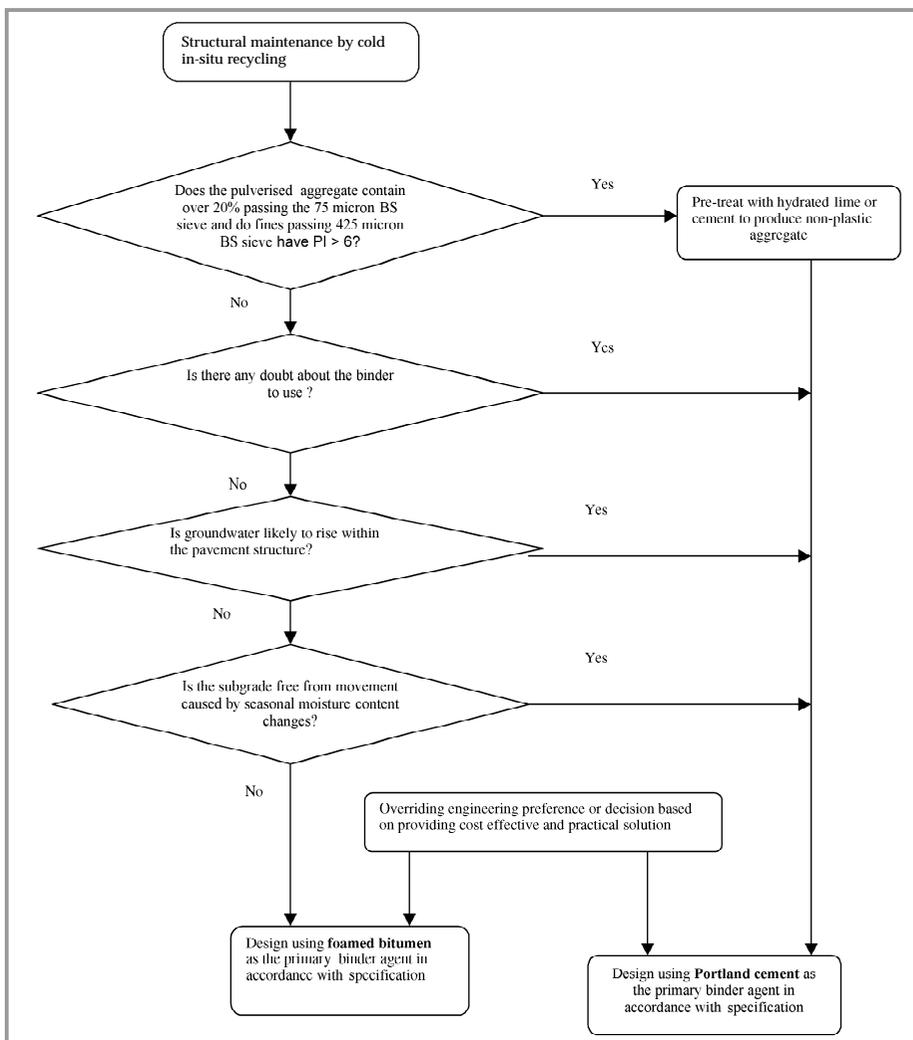


Figure 4: Flow chart for choosing type of stabilising agent (Extracted from Reference No.3)

cracks, the effective modulus of the cement treated layer is reduced in the estimation of the structural life of the pavement.

5.1.2 BITUMINOUS STABILISING AGENTS

There are two types of bituminous stabilising agents commonly used, namely bitumen emulsion and foamed bitumen. The reason for using bitumen emulsion is to make it possible to mix bitumen with cold moist material. The main advantages of using foamed bitumen over bitumen emulsion are reduction in binder and transportation costs (foamed bitumen uses normal 80/100 penetration-grade bitumen), can be opened to traffic immediately after compaction (curing time not necessary) and remains workable for extended periods (do not need to be used immediately) and can be worked in

adverse weather condition without the bitumen washing out of the aggregate. Normally, cement or lime is added in small amounts to assist the dispersion of bitumen that adhere to fine particles (below 0.075mm fraction). This results in bitumen bound filler that acts as a mortar between coarse particles.

6.0 CONSTRUCTION

The required equipment train for CIPR and the recycling process has been explained in the preceding sections. The actual recycling works require proper planning and the following aspects need to be considered prior to the actual recycling work:

- Removal/protection of manhole and other such structures to allow the recycling works to proceed without interruption
- Pre-shaping road surfaces that are badly out of shape to regulate the

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thickness of the recycled layer and to establish the required final shape. This can be achieved by pre-milling the existing surface, importing new material to correct surface shape and grading of the recycled material or pre-pulverising the existing pavement.

A trial lay of about 150m in length is normally carried out first to ensure that the properties of the recycled materials behave as per laboratory design and meet the specification requirements. Among the aspects considered include grading of the recycled material, compaction requirements of the material and bulking behaviour of the material.

During the actual recycling, among the main items considered include treatment of joints, compaction and finishing of the recycled layer.

Joints affect the structural integrity of the recycled layer and minimum overlap lengths are required. There are two main types of joints in CIPR, namely lateral and longitudinal joints. Longitudinal joints (parallel to the centerline of the road) are dictated by the width of the milling drum of the recycler, (typically 2.5m) which is normally smaller than the width of the pavement. A 4.5m carriageway (3.5m and 1m shoulder) will require two recycling passes, with 0.5m overlap. The minimum requirement for an overlap is 150mm to ensure continuity between adjacent cuts. Lateral joints arise when the recycling operations stops or is interrupted. It is recommended that the recycling train should be reversed into the previously recycled material by at least the diameter of the milling drum (about 1.5m) [4].

Compaction of the recycled layer is important because it affects the future performance of the pavement. Poor compaction leads to early rutting and increased in permeability, which in turn, promotes moisture damage, early aging of bituminous stabilising agents and early carbonation of cementitious agents, causing premature failure of the pavement. Two important factors in achieving the required density is the control of the optimum moisture content and the correct application of suitable rollers to achieve the required compacting effort. A compactometer fitted to the primary roller is a reliable method to measure peak



Figure 5: Recycled material (uncompacted) at the rear of the recycling machine



Figure 6: Compacting the recycled material with a roller



Figure 7: Finished recycled layer after compaction

density and to prevent over-compaction. Nuclear density gauges is unreliable because it overstates the moisture measurement of recycled layer due to the presence of bitumen (bitumen stabilise layer) while sand replacement method is labour intensive and time-consuming.

Finishing-off a recycled layer is achieved by pneumatic rolling (including watering) to produce a tightly-knit surface texture to shed water. The requirements for finishing the recycled layer surface is dependant on the nature of the material and the choice of stabilising agent.

For example, high bituminous content tends to produce coarse and cohesionless material, leading to finishing difficulties (identified during trial lay). This can be addressed by spreading fine materials prior to the actual recycling process to modify the product. For cement-treated

material, curing for a period of seven (7) days (using curing membrane) is important to prevent shrinkage cracks from developing on the surface of the recycled material.

7.0 QUALITY CONTROL

During the recycling process, a series of checks are made for the following: depth of recycling, amount of water and stabilising agents applied, quality of mixing, correct formation of lateral joints.

Apart from the above, a series of quality control tests are carried out to ensure that the recycled layer will perform as expected in the long term (that is meeting the design life of the rehabilitated pavement). Loose samples of the recycled material are taken immediately during the process operations for laboratory tests while core samples from the compacted recycled layer after the material has gained sufficient strength (normally after 72 hours). These tests are as follows [5]:

The following tables summarise the typical engineering properties of three common materials used in CIPR, stabilised with cement only and bitumen stabilised (emulsion and foam) with cement added (4):

8.0 ADVANTAGES AND DISADVANTAGES OF CIPR

Advantages of CIPR

The advantages of cold in-place recycling are the following:

- (1) Conservation of energy and materials (aggregates, asphalt and transport fuel),
- (2) No milling waste disposal,
- (3) Pavement geometrics are preserved or restored,
- (4) Most pavement distresses such as cracks, rutting and potholes can be corrected,
- (5) Structural improvements can be made without significantly affecting the geometry,
- (7) Existing base problems can be corrected,
- (8) The process is relatively cheap compared to conventional methods such as reconstruction.

Disadvantages of CIPR

The disadvantages of CIPR include the following:

General Tests	Typical Specification Requirements
Moisture Content (BS 1377)	OMC \pm 20% of JDM
Grading (BS 1377)	As per approved JSM
Field Compaction	> 97% of JDM
Sand Replacement for Density (BS 1377)	
Additional tests for bituminous stabilising agent	
Effective Bitumen Content (Foam Bitumen)	\pm 0.5% of JDM
Indirect Tensile Strength (Loose Sample) ASTM 4123	> 200 MPa (unsoaked) > 100 MPa (soaked)
Stability (from loose sample) ASTM D1559	> 450 kg
Additional tests for cementitious stabilising agent	
Quantity of Cement (Optimum Cement Content)	\pm 0.5% of JDM
Unconfined Compressive Strength (BS 1881 Pt.116)	> 2.8 MPa



Figure 8: Indirect tensile testing of foamed bitumen briquette

- (1) High acquisition cost of the CIPR equipment,
- (2) A dedicated and skilled team of operators/workers is required,
- (3) Existing pavement cross-section and properties must be relatively homogenous for the process,
- (4) Extra care must be taken where there are manholes and services at shallow depth,
- (5) Moisture content of recycled materials must be controlled,
- (6) Wearing course is required on top of

Test Parameter	RAP/CRUSHED STONE (50/50 blend)		
	Cement Stabilised 2-2 1/2 % cement	Bitumen stabilised	
		2 1/2-5 % emulsion plus 1-1 1/2 % cement	1 1/2-3% foam plus 1 % cement
Density % modified AASHTO	96 to 98	98-100	98 to 102
Unconfined Compressive Strength MPa	1.5 to 3	n/a	n/a
Indirect Tensile Strength (ITS) kPa	n/a	350 to 750	350 to 800
Retained Strength %	n/a	> 75	>75
Resilient modulus MPa	~5000(Pre-cracked)	2500 to 5000	2500 to 5000

Test Parameter	CRUSHED STONE(Maximum size 53 mm, PLASTICITY Index <6, CBR >80)		
	Cement Stabilised 2-3 % cement	Bitumen stabilised	
		3 1/2-6 % emulsion plus 1-1 1/2 % cement	1 1/2-3% foam plus 1 % cement
Density % modified AASHTO	96 to 98	98-100	98 to 102
Unconfined Compressive Strength MPa	1.5 to 3	n/a	n/a
Indirect Tensile Strength (ITS) kPa	n/a	400 to 800	400 to 900
Retained Strength %	n/a	> 60	>60
Resilient modulus MPa	~5000(Pre-cracked)	3000 to 6000	3000 to 6000

Test Parameter	NATURAL GRAVEL. (Plasticity Index < 10, CBR~30)		
	Cement Stabilised 3-4 % cement	Bitumen stabilised	
		4-7 % emulsion plus 1-1 1/2 % cement	1 1/2-3% foam plus 1 % cement
Density % modified AASHTO	95 to 97	97-100	98 to 100
Unconfined Compressive Strength MPa	1.5 to 3	n/a	n/a
Indirect Tensile Strength (ITS) kPa	n/a	250 to 500	250 to 500
Retained Strength %	n/a	> 50	>50
Resilient modulus MPa	~4000(Pre-cracked)	2000 to 4000	2000 to 4000

the recycled layer to provide the smooth riding quality.

9.0 CONCLUSION

CIPR is an economical and environmentally sound alternative to conventional rehabilitation methods such as structural overlay or reconstruction. Its use in Malaysia is expected to increase in the future as more pavement rehabilitation works instead of new roads will be carried out to preserve the integrity of the pavement structure and to extend the pavement life. However, an adequate understanding of the CIPR process, its suitability and limitations is essential for the correct pavement candidate to be chosen, for the works to be carried out successfully and for the pavement to perform satisfactorily. ■

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