Review of Cold In-Place Recycling:
Environmental, Economical, and Performance Analysis

Introduction

Cold in-place recycling (CIR) is a rehabilitation method that recycles existing asphalt pavement in-place, which reduces pavement rehabilitation spending by recycling 100% of the asphalt that agencies already own. The CIR process involves milling an existing asphalt road to a desired depth, then the asphalt millings are sized and screened. Bitumen binder (emulsified asphalt) is then added by calibrated computerized weigh scales. The addition of new binder rejuvenates the deteriorated pavement. After the addition of binder, the new homogenous mixture is placed uniformly with a pickup elevator and highway class paver. The pavement is then compacted and cured; a wearing course is then applied after the pavement has cured.

CIR has been in use since the late 1970s [1], but the use of CIR varies by region. For example, the Ministry of Transportation Ontario has been using the CIR process since 1990 [2] and as of 2015 had laid down 1,953 two lane-km of road using cold in-place recycling technology [3].

Environmental Analysis

When compared to other traditional pavement rehabilitation such as mill and inlays, CIR emits fewer greenhouse gas emissions, uses less energy, virgin aggregate, and asphalt binder. Using recycled asphalt reduces waste and reduces the environmental impact of road construction. When the entire process is considered, the CIR process emits an equivalent of 5 to 20kg of CO_2 whereas hot mix asphalts emit an equivalent of 45 to 50kg of CO_2 per tonne of material laid, even when the hot mix process uses recycled asphalt [4]. On average, hot mix asphalt applications were found to emit 280% more CO_2 than CIR per tonne of material laid [4]. Similarly, another study found that on average a 100mm mill and 130mm hot mix asphalt inlay has been evaluated to emit over two times more greenhouse gas emissions than the CIR process per standard two lane-km [2].

The CIR process also consumes less energy than traditional hot mix rehabilitation applications. A Canadian study found the CIR process to use an average of 243% less energy than hot mix applications per tonne of material laid [4]. Due to the in-place technology, CIR processes consumes 41 to 62% less transportation energy than mill and inlay processes [5]. Studies evaluating energy consumption have consistently determined that CIR uses less energy than hot mix applications.

Additionally, the CIR process reduces the use of virgin aggregate and asphalt cement which are non-renewable resources. When no virgin aggregate is used in the CIR mixture, the CIR process uses 62% less aggregate than a 130mm hot mix asphalt mill and inlay. Even when virgin aggregate is used in the CIR mix, the CIR process still emits a substantially lower amount of greenhouse gases than hot mix asphalt processes [5].

The Government of Canada is committed to reducing the impact of climate change, including using green technologies and reducing greenhouse gas emissions [6]. Canada participated in the United Nations Climate Change Conference in Paris in 2015 and signed the Paris Agreement in 2016. CIR is a pavement rehabilitation technology that reduces greenhouse gas emissions and uses less energy, which aligns with the Government of Canada's goal to take action on climate change.

Economics

The cost savings of the CIR process have been widely reported, and the savings have led to the CIR process being used in various locations in North America (e.g. Alberta [7], Manitoba [8], Ontario [9, 10], Nova Scotia [11], and numerous states in the United States [5, 12]). The difference in cost between CIR and hot mix asphalt options has been evaluated for numerous projects. The cost difference depends on many factors including location, asphalt and aggregate costs, and equipment availability. The initial cost of CIR projects are lower than hot mix asphalt applications such as mill and inlay [5]. For example, in Ontario CIR initial project costs are an average of 42% lower than mill and inlay [2].

The life-cycle costs of CIR are also lower than hot mix asphalt applications. In Ontario, the entire life-cycle of CIR roads was found to cost 22% to 25% than less than mill and overlays [2, 10]. Similarly, the life-cycle costs of CIR roads were determined to be approximately 20% less than mill and inlay in New York State [5]. In northwestern Pennsylvania it was found that on average CIR cost 24% less than hot mix asphalt per ton of asphalt mix [12].

CIR is an excellent choice when good quality aggregates are not locally available, as little to no virgin aggregate may be required. Because the process of CIR is done in-place, there is less heavy road construction traffic. Therefore, less damage is done to the existing roads. Virgin aggregate may be required for CIR projects when the asphalt content of the road to be recycled is already high and the existing road is soft or when the gradation of the recycled mix is poor. The cost of CIR increases slightly when virgin aggregate is required (e.g. 10.5 to 13.9%) but the cost is still less than traditional mill and inlays [5].

The Government of Canada's goal to take action on climate change will change how fuels and greenhouse gas emissions are taxed in the future. For example, the Government of Alberta will be introducing a carbon tax on fuel. Carbon levy taxes will add a charge of $20 per tonne of fuel as of January 2017 and $30 per tonne as of January 2018 [13]. CIR will provide additional savings over the traditional mill and inlay through reduced fuel consumption for the CIR process.

The initial construction costs and overall life-cycle costs of the CIR process have repeatedly been reported as lower than the cost of mill and inlay. The CIR process is a sound economic investment for both short term and long term cost savings.

Construction Process

The CIR construction process starts with milling the existing damaged pavement to a specified depth. The milled pavement is collected, crushed, and screened to the appropriate size (typically 37mm or smaller [1]). The recycled pavement is then mixed with emulsified asphalt. In some regions, other additives such as Portland cement or lime are also incorporated. The new mixture is windrowed, spread out, and compacted. CIR is typically between 75 to 150mm thick when placed. After curing, a wearing course is applied. Typically, a 50mm hot mix asphalt overlay is applied as the wearing course. Alternatively, a double seal coat may be applied as the wearing course. Figure 1 shows the construction process using multi-stage equipment.

Figure 1. CIR construction recycling existing pavement.

Finding a candidate road for CIR typically requires visual inspection of the existing pavement as well as a records review of the road history. Core samples of the existing pavement will be taken and tested before any CIR project is initiated in order to produce a mix design outlining the amount of binder to be added. Roads that have an unstable granular base are not good candidates for CIR and these roads may require full depth reclamation or total reconstruction. A road which qualified as a good candidate for CIR is shown in Figure 2. Roads that have one or more of the following conditions may be good candidates for CIR:

- Wheel path fatigue cracks
- Transverse cracks
- Alligator cracks
- Shoving
- Potholes
- Rutting
- Surface breaks

Figure 2. A road which qualified for reconstruction using CIR (Highway 53 near Rimby, Alberta). The right hand lane shows what the road looked like before being recycled.

The CIR mix design typically contains 1.5 to 2.2% emulsified asphalt as the binding agent [5], although more or less emulsified asphalt may be required depending on the composition of the existing pavement. Field adjustments may be needed due to variations in the existing asphalt pavement. These adjustments are determined by an experienced contactor or engineer working on the project. CIR cannot be applied during cold weather; for example Ontario specifies that the air temperature must be at least 10ºC when CIR is applied [14].

The disruption to traffic flow is minimal with the CIR process. Because everything is performed in-place, the production rate is high and there is less construction traffic on and near the site. Traffic can return as soon as the CIR mixture is compacted [2]. The CIR process typically accomplishes three lane-km per day [15].

Performance

Excellent roads have been laid down all over Canada via the CIR process. Many CIR roads do not require resurfacing for 15 or more years after initial construction, which is comparable to traditional hot mix treatments [2, 10, 12].

Freeze-thaw cycles are a major cause of reflective cracks in roads in Canada and CIR reduces reflective cracking. For example, CIR was used to produce a 5.5 km road in Calgary, Alberta in 2011 and one year later there were no observed cracks [7]. Typically after one year of mill and inlay, there are reflective cracks, including transverse cracks. CIR has been repeatedly shown to be the most effective process to mitigate reflective cracking in cold weather climates [1]. In Ottawa-Carleton, Ontario the number of transverse cracks were measured on CIR roads and roads treated with a hot mix asphalt overlay for the first six years after application. The number of cracks per kilometer per year for the hot mix asphalt overlay roads was almost twice the amount of the CIR roads [10]. Another study in Ontario which analyzed over 800 lane-km found similar results, where after approximately 14 years of service CIR roads had approximately 150 transverse cracks per km and roads with hot mix overlays had approximately 350 transverse cracks per km [15]. Additionally, the CIR roads showed fewer transverse cracks than newly constructed roads over their life-cycle [15]. In Pennsylvania, numerous roads were surveyed over time and CIR roads had two to three times fewer cracks than roads with traditional hot mix asphalt applications [12]. The cracks on the CIR roads did not begin to appear until three years after construction.

Figure 3. Excellent pavement condition seen in a road which had been recycled using CIR 14 years prior (Highway 91, Simcoe County, Ontario).

The reduction in reflective cracking in CIR roads is likely due to the flexibility in the road. Even though CIR roads exhibit the quality of flexibility, they gain stiffness over time and can have modulus values which are comparable to hot mix asphalt [12]. Average deflection results of CIR roads have been measured as the same as or less than before the road was recycled, indicating that the structural strength of the road is unchanged or improved with CIR [1]. Structural strength increases as the CIR mixture cures and also increases with a 50mm hot mix overlay [15].

The smoothness of an existing asphalt road can be significantly improved when a road is rehabilitated by CIR. This in turn produces a road which is safer and will last longer. The smoothness of a road can be measured using the international roughness index (IRI). For example, using CIR on a road in Calgary, Alberta increased the smoothness of a road by 63% from the condition of the original asphalt pavement.

The resulting road initially had an IRI of 0.83mm/m. After one year, the smoothness of the road in Calgary was 0.87mm/m and therefore had barely changed [7]. Near Perth, Ontario, no difference was found in smoothness of a CIR road was measured after one year and after five years of service, with an average IRI of 1.0mm/m [16]. In comparison to hot mix asphalt, the smoothness of CIR roads has been determined to be similar to mill and inlay roads. In a ten year life-span, the IRI of roads in Ontario averaged 1.00 to 1.30mm/m for CIR and 0.84 to 1.18mm/m for mill and inlay [2].

The pavement condition index (PCI) assesses the surface condition and smoothness of a road. CIR roads 11 to 15 years old evaluated in New York State did not have significantly different PCI values when compared to mill and inlay or two course overlay roads [5]. The IRI and PCI values demonstrate that the smoothness of an existing road is greatly improved with CIR rehabilitation and the surface condition is comparable to traditional hot mix applications throughout the roads' life-cycle.

Many CIR mixtures have been reported to have similar air voids but longer fatigue lives than traditional hot mix asphalt [1]. In Ontario, the air voids in compacted CIR mixtures have been typically reported as 12 to 15% [15]. Some studies have found that CIR mixtures have higher air voids (e.g. 15.8% [7]) in comparison to hot mix asphalt (e.g. 3 to 5%) and therefore could be more susceptible to damage if water enters the CIR layer [5]. However, numerous reported results on CIR roads have shown that cracking is minimal [1, 10, 12, 15] and therefore water entering air voids does not appear to affect performance.

Performance evaluations of CIR roads has been an ongoing process for decades. In most aspects CIR roads perform similarly to mill and inlay roads, but CIR roads have shown better crack mitigation [1]. The CIR process produces high quality roads which are proven to last.

Conclusion

The CIR process reduces greenhouse gas emissions, uses less energy, makes good use of existing damaged pavement, requires a short amount of construction time, and reduces the use of non-renewable resources. The initial construction costs and life-cycle costs for CIR are substantially less than the cost of traditional hot mix rehabilitation processes. A wide array of studies have shown that CIR roads perform well and last a long time. This innovative technology has been used for decades and has proven to be a valuable investment for a strong sustainable road network.

"CIR meets the criteria for sustainable pavement: safe, efficient, economic, environmentally friendly pavement process that meets the needs of the present-day users without compromising those of future generations." [2]

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