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Quantifying the environmental burdens of the hot mix asphalt (HMA) pavements and the production of warm mix asphalt (WMA)

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Abstract

Asphalt pavement has significant environmental burdens throughout its life cycle. A life cycle assessment (LCA) model is used to quantify the environmental burdens for material, construction, maintenance and use phases of hot mix asphalt (HMA) pavement. Two peer reviewed journals have been used to collect all of the inventory loadings as an input for the LCA model and ten impact categories have been evaluated as output. The result of the inventory analysis is a summary of all inflows and outflows related to the "functional unit". The result of each impact category is the total of all the individually characterized inventory loadings in each category. Each life cycle phase of HMA pavement has been quantified on these ten impact categories and a comparison provided among the phases to understand the percentage contribution to the environment. Human and eco toxicity values are higher for the material phase, whereas the rest of the impact categories are significant in the use phase. The material phase contributes 97% of the overall human toxicity in water from standpoint of asphalt pavements, whereas in the material phase the production of bitumen is responsible for 90% human and eco toxicity in terms of air based burden. As a solution, the life cycle inventory of WMA has been estimated and reduction only done in HMA production. From analysis, it was estimated that WMA provides a reduction of 29% on the acidification impact and 25% reduction on both fossil fuel consumption and photo oxidant formation impact of HMA.

Keywords: Life cycle analysis; Environmental burdens; Inventories; HMA; Impacts; WMA

1. Introduction

Highway networks cover over eight million lane-miles while supporting three million vehicle-miles each year in the United States [20]. Asphalt and cement concrete are the two most common materials used for pavement construction. Approximately 83% of all pavements and streets in the United States are made of flexible type (asphalt wearing surface), 7% are rigid type (Portland cement concrete roadway with or without an asphalt wearing surface), and nearly 10% are of composite type like asphalt surface on Portland cement concrete base [25]. According to National Asphalt Pavement Association (NAPA), asphalt materials currently cover more than 94% of the paved roads in the United States. For building an asphalt pavement consideration of the environmental consequences through all phases of its development, from material extraction to construction, from construction to operation and service is important. Lately researchers and engineers have been considering the environment impacts of engineering decisions. Life cycle assessment (LCA) can be used as a method to assess the environmental effects of an asphalt pavement system over its entire life period [10,14]. It is being accepted and applied by the

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pavement industry, to quantify and compare the environmental effects of asphalt products and processes.

Several researchers have studied the effects on the environment due to materials, construction, maintenance, recycling, use and end of life phase of asphalt pavement in terms of energy and air emissions [2,3,7,23,24,4,22,19,6,21,13]. Also, some other studies have focused on not all but few life cycle phases of asphalt pavement in terms of energy, air emission or raw materials [9,15,16,25,1,5,10]. Among the aforementioned studies few also compare the environmental impact between asphalt and concrete pavement. Most studies have utilized LCA models to estimate the environmental impacts by quantifying energy consumption, atmospheric emissions and waste generation. However, ecological impacts or emissions in water in terms of toxicity for human and ecosystem generally been excluded from these studies. One study has performed the ecological impact for materials (extraction, manufacturing, transportation) and construction phase of asphalt pavement in terms of inventory loadings [12].

The aim of this study is to quantify the environmental burdens of four phases (material, construction, maintenance and use) of hot mix asphalt (HMA) pavement in terms of energy, air emissions and water emissions using the LCA model and to compare the impacts among those phases. It is hypothesized that material and use phase should generate more emissions as compared to the other two phases of HMA pavement. To achieve this objective, a life cycle inventory that quantifies the energy, material phase inputs (emissions during aggregate extraction, bitumen production and HMA production), construction phase inputs, maintenance phase inputs and use phase inputs (normal traffic, traffic disruption and lighting), were developed. Based on this inventory loading, impact assessments were evaluated on ten categories. In addition, the percentage improvement that would result by implementing warm mix asphalt (WMA) technology instead of HMA has been evaluated on four impact categories.

2. Asphalt pavement

Asphalt or flexible pavements have low or negligible flexural strength or are rather flexible in their structural action under the loads. The mechanism of an asphalt pavement is to transmit the vertical or compressive stresses to the lower layers by grain to grain transfer through the points of contact in the granular structure. A typical asphalt pavement consists of four components: (i) soil subgrade, (ii) sub-base course, (iii) base course, and (iv) surface course.

The subgrade should provide adequate stiffness because it provides resistance to deflection, allowing rollers to produce a firm compaction of all layers. The soil subgrade is critical to the overall performance of an asphalt pavement. It essentially provides for a strong foundation and serves as a working platform for dump trucks and supports traffic loads. Proper design and construction of the foundation are keys in preventing volume changes due to wet-dry cycles in expansive clays and freeze-thaw cycles in frost susceptible soils. Lime, cement or fly ash is frequently used to stabilize the sub grade if additional support is necessary. Base and sub-base courses are constructed using asphalt concrete, crushed stones or granular materials or gravels. The surface course is usually composed of HMA because this layer is directly subjected to traffic loads.

HMA is a combination of approximately 95% stone, sand, or gravel bound together by asphalt cement. Asphalt cement is heated and mixed with the aggregate at a HMA facility. After mixing, the HMA is loaded into trucks and transported to the worksite. The trucks dump the HMA at the site and in front of paving machines. HMA is placed and compacted using a heavy roller.

Asphalt is the residual fraction obtained from the fractional distillation of crude oil. It can also be found from natural resources. It is the heaviest residue separated from crude oil. It is highly viscous, black, sticky and entirely soluble in carbon disulfide and composed primarily of highly condensed polycyclic aromatic hydrocarbons. It is primarily used for paving roads because of its good waterproofing and adhesion properties.

3. Life cycle phases of asphalt pavement

Asphalt pavement has five life cycle phases. These are

(i) Material phase (bitumen, aggregate and HMA production)
(ii) Paving or construction phase
(iii) Maintenance phase
(iv) Use phase
(v) End of life phase

The life cycle begins with bitumen being processed from the crude oil or natural sources. Aggregate is collected from the natural sources. Collected bitumen and aggregate are transported to the HMA plant. Subsequently, HMA is manufactured at 150–190 °C. From the HMA plant, HMA is transported to the construction site. HMA is placed on the selected site and the paver machine is used to compact it. Pavement is opened to the traffic when the construction of asphalt pavement is done. Depending on the type and crack on the pavement, routine maintenance takes place after a certain interval of time. Generally there is no end of life for asphalt pavement because it is 100% recyclable [2]. It can be reused for the maintenance purpose or for new asphalt pavement construction.

4. Goal and scope of the study

The main purpose of the study is to assess the environmental impact of an asphalt pavement. The aim is to identify and quantify the environmental impact of each life phase of an asphalt pavement and to make a comparison among these phases. Generally, the environmental impact